Promoting physical activity and preventing falls among older adults in a nursing home setting: Rationale, development, and protocol for implementation of the BeSt Age mobile application

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Abstract

Background: A majority of nursing home residents do not fulfill physical activity guidelines. Many existing interventions to promote physical activity and prevent falls in nursing home residents have low adherence rates, lack theoretical foundation, or require a large amount of time from staff for preparation and/ or delivery.

Objective: To describe the rationale, development steps, and implementation approach of the BeStAge app through a cluster randomized controlled trial (cRCT), as well as to provide baseline characteristics of the study sample and discuss possible implications for further app developments.

Methods: We iteratively developed a novel, tablet-based mobile application named BeSt Age app that enables nursing home staff to deliver individualized physical exercise training to residents with or without motor or/ and cognitive impairments. The app was designed and developed based on an intervention-mapping approach. A needs assessment was performed, followed by defining objectives, theory-based methods, program development, implementation, and evaluation. We took several steps to ensure that the app was based on a sound theoretical background, as well as results derived from and limitations identified in prior empirical research. For implementation and evaluation purposes, we conducted a cRCT, and results from the cRCT will be used to examine the effectiveness of the app with regard to different outcomes of interest. Primary outcomes among participating nursing home residents are quality of life, fall risk evaluated through two performance-oriented balance tests, and fall incidence. Secondary outcomes include motor performance, cognition, activities of daily living, life space/ physical activity behavior, and fall efficacy, amongst others.

Results: 229 older adults from 19 different nursing homes (171 females, 58 males; mean age 85 years) participated in the cRCT. The intervention group (IG; N = 137 from 11 nursing homes) received a 12-week intervention with the BeSt Age app in small, homogenous groups of 5-7 nursing home residents, with two exercise sessions per week, each lasting 25-30 minutes. The control group (CG; N = 92 from 8 nursing homes) received usual care. At baseline, the IG had a statistically significantly larger number of females, participants had a higher body mass index, and more participants rated attending physical activity programs as important; there were no further statistically significant differences between IG and CG. Results with regard to the effectiveness of the BeSt Age app are expected to be published in summer/ fall of 2025.

Conclusions: If proven effective, the BeSt Age app may be a viable solution for physical activity promotion and fall prevention among older adults residing in nursing homes, thereby ultimately contributing to maintaining quality of life and overall well-being in this vulnerable population. The app can support nursing home staff in delivering exercise training to residents with minimal additional workload and without requiring specific resources. Clinical Trial: German National Register of Clinical Trials (DRKS00032349)

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ABSTRACT

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Conclusions: If proven effective, the BeSt Age app may be a viable solution for physical activity promotion and fall prevention among older adults residing in nursing homes, thereby ultimately contributing to maintaining quality of life and overall well-being in this vulnerable population. The app can support nursing home staff in delivering exercise training to residents with minimal additional workload and without requiring specific resources.

Trial registration: German National Register of Clinical Trials (DRKS00032349)

Keywords: mobile health; physical activity; fall prevention; older adults; nursing homes; cluster randomized controlled trial

INTRODUCTION

Regular engagement in physical activity from young through middle into old adulthood is of high importance for an independent, self-determined life and maintained functional performance [1]. Research has shown that physical activity has various beneficial effects on physical as well as mental health and well-being in older adults [2], and may delay age-related cognitive decline [3]. Physical activity is also associated with a decreased risk of falls in community-dwelling older adults [4] and nursing home residents [5, 6], albeit conflicting results for the latter group have been reported [7]. Nevertheless, it is well established that falls are very common among individuals residing in nursing homes [8], and are associated with adverse health outcomes such as increased risk of morbidity and mortality [9].

The World Health Organization recommends 150 to 300 minutes of moderate to high-intensity aerobic physical activity per week for adults, and moderate strength training on two or more days per week that involves all major muscle groups of upper and lower extremities [10]. In addition, with regard to fall prevention, persons aged 65 years and older should perform activities that can improve functional balance and proprioception on at least three days per week [10]. A minimum of 4600 steps per day, averaged over a week of free-living behavior, has been recommended for older adults by an expert group [11]. Furthermore, another expert taskforce from the International Association of Gerontology and Geriatrics - Global Aging Research Network and the European Region Clinical Section has published physical activity recommendations for older adults residing in long-term care facilities [12]. They defined two different levels of recommendations, i.e., a first set aiming at reducing sedentary behaviors for all residents in long-term care facilities, and a second set aiming to establish specific, evidence-based guidelines for exercise training for well-defined subgroups of residents. To this end, they recommend multicomponent training, particularly focusing on strength, aerobic endurance, balance, and flexibility. This training should be of moderate intensity, carried out at a frequency of at least twice a week, and with a duration of 35 to 45 minutes per session.

However, despite the widely acknowledged benefits of physical activity, and despite many individuals having intentions to engage in physical activity, most fail to follow through; a phenomenon referred to by (sports-)psychologists as the intention-behavior gap [13]. It is well known that older adults do not engage in a sufficient amount of physical activity, and this is particularly true for those residing in care facilities. For example, a literature review showed that care facility residents only engage in low levels and intensities of physical activity, with

numbers of steps per day averaging between 385 and 3387 across studies, and that there is very little variation in movement patterns [14]. Another review reported daily sedentary times of 11.6 hours among residents in high-level care facilities such as nursing homes [15]. Furthermore, a study conducted in German nursing homes utilizing sensor-based assessment revealed that residents' movement space was mainly restricted to their personal rooms and the adjoining residential units during 90% of the daytime [16].

This lack of physical activity among nursing home residents is alarming, particularly since the negative consequences of sedentariness may be accelerated by age-related physical and cognitive decline, thereby further increasing care dependency and burden for caregivers and family members [17]. Different factors have been discussed in the literature that may impact physical inactivity and sedentariness [18-20], including but not limited to personal characteristics of older adults (e.g., physical and mental health status), interpersonal aspects such as company or social network, physical environment (e.g., access to green spaces), or organizational barriers such as nursing home staff shortage or time constraints. Recently, a systematic literature review of caregiver-provided exercise interventions for individuals with dementia reported that the main barriers to the implementation of such exercise interventions were a lack of knowledge about positive effects of physical activity or insufficient time and resources for implementation among caregivers [21], albeit also acknowledging that all stakeholders considered physical activity interventions as useful and relevant.

To date, a growing body of interventions and programs aimed at promoting physical activity, preventing falls, or improving motor performance is being more widely implemented in care settings, and different literature reviews are available focusing on the effectiveness of such programs on various outcomes of interest, e.g., quality of life [22] or mental health and cognition [23]. However, there are still several challenges that need to be addressed. One challenge, for example, is low adherence. To this end, a French study revealed that only 1914 of 5402 older nursing home residents participated in physical activity programs provided by their nursing homes, and that classes were only offered once per week or less, on average [24]. Another limitation is a lack of theory-based or derived interventions, such as interventions incorporating behavior change techniques [25]. For example, researchers from Taiwan recently developed a motivation theory-based walking intervention that enhanced the self-efficacy of older adults in residential care facilities, and it was perceived as helpful in physical activity engagement [26]. Further limitations, as also mentioned above, include but are not limited to lack of knowledge among caregivers along with insufficient time and

resources for implementation of physical exercise [21], and use of ‘one-fits-all’ physical exercise programs rather than individualized programs that are deliberately tailored to the needs and preferences of older adults residing in nursing homes which may have higher effectiveness [27].

One approach to potentially overcome some of these limitations and challenges of physical exercise implementation in care settings may be the use of assistive digital technologies such as mobile applications. These technologies can support caregivers who may not have prior expertise or knowledge on physical activity training, and/ or only very limited time in delivering exercise interventions to nursing home residents [28]. Indeed, literature reviews have shown promising results of using e- and m-health interventions, mainly exergaming, to promote physical activity and prevent falls in nursing home settings [29]. Moreover, one study examined the usability as well as the effects of an app-derived, physical activity intervention for older adults with dementia residing in nursing homes, but the validity of results was limited by the small study sample size [28, 30]. Other studies have shown that nursing staff are willing to use digital and assistive technologies, but that access to such technologies including WiFi is limited in nursing home settings. To maximize acceptance, it is crucial to involve nursing staff in the development process, and provide adequate training and testing opportunities, tailored to their (previous) experience and affinity for technology [28, 31, 32]. Overall, even though preliminary results regarding usability, acceptability, and/ or effectiveness are promising, digital interventions for physical activity promotion in older adults remain understudied, and existing solutions are too heterogeneous for meaningful comparison of results [33], thereby limiting evidence. Furthermore, little is known about the practical application [34], accessibility, acceptability, and sustainability of such solutions [35], and many care institutions are thus still hesitant to adopt these innovations [36, 37].

To address some of the challenges and limitations related to physical exercise implementation in care settings as outlined above, we have iteratively developed and implemented a mobile application called the BeSt Age app and examined its effectiveness in a cluster randomized controlled trial (cRCT). The aim of this manuscript is to describe the rationale, development steps, and implementation of the BeSt Age app, as well as to provide an overview of baseline characteristics of the cRCT study sample and discuss future implications.

METHODS

Rationale for and development of the BeSt Age app

To address gaps in prior research as outlined above, the tablet-based BeSt Age app was designed with the overarching aim of supporting care staff in delivering an individualized physical exercise program to small, homogenous groups of nursing home residents. Based on an intervention-mapping approach [38], a needs assessment was performed, followed by defining objectives, theory-based methods, program development, implementation, and evaluation. Thus, we took the following steps to ensure that the app was designed and developed based on a sound theoretical background, as well as results derived from and limitations identified in prior empirical research.

First, we conducted an online survey with 200 nursing home staff across Germany to examine previous experiences with and willingness to use digital solutions, including but not limited to the purpose of physical activity promotion and fall prevention, as well as perceived possible risks, attitudes, and expectations in this regard [31, 32]. We also inquired about affinity for technology or technical equipment available in nursing homes. We then conducted an interview study with stakeholders (i.e., three managers, six employees providing care for residents, and ten residents) from seven different nursing homes to gather information about existing physical activity programs that they may have implemented in their institutions, and to identify prior experience, needs, expectations, fears and possible barriers to using digital technology. The results from both the online survey and interview study were used to ensure that our app would have a high acceptability and feasibility. Furthermore, we carried out a two-week pilot study in two nursing homes using a prototype of the Best Age app to examine its feasibility, usability, and user experience.

Second, we defined the objectives of the Best Age app. Those included the delivery of physical exercise tailored to the needs and preferences of nursing home residents (rather than ‘one-fits-all” exercise) by nursing home staff; creation of small groups of residents with comparable motor and cognitive performance status using an in-built algorithm; inclusion of a wide range of nursing home residents, e.g., also those using a wheelchair or walking aids (we only excluded persons with very severe motor, neurological and/ or cognitive impairments and disorders); and a multimodal exercise program including both motor and cognitive stimulation.

Third, we took several theoretical considerations into account that have been the foundation of lifestyle interventions aimed at improving health-related outcomes such as social cognitive theory [39], ensuring that our app is evidence-based, comprehensive, and tailored to meet the objectives as outlined above. Furthermore, app content was developed based on the self-determination theory [40], as it fosters intrinsic motivation by addressing three

fundamental psychological needs, i.e., autonomy (users choose activities), competence (activities are tailored to ability levels), and relatedness (social support through group activities). Also, the COM-B model [41] was considered for app development. According to this model, behavior change depends on capability (physical and psychological), opportunity (social and physical environment), and motivation. We designed the app in a way that it would target all three components by simplifying exercise selection, embedding social elements, and using gamification features to enhance motivation. Moreover, basic theories on enhancing acceptance of technology such as the Technology Acceptance Model [42], as well as published physical activity recommendations for older adults residing in long-term care facilities [12] were taken into account.

Fourth, regarding the exercise program development, we drew on our expertise from the InCoPE app that our group had developed and evaluated prior to the BeSt Age app. Briefly, the InCoPE app was designed to enable nursing home staff to deliver an individualized exercise program to small, homogenous groups of nursing home residents with dementia [28, 30, 43]. In contrast, the BeSt Age app was developed to enable nursing home staff to deliver an individualized exercise program to nursing home residents regardless of their cognitive impairment status. Thus, we consider the BeSt Age to be more inclusive than our previously developed InCoPE app. When designing and developing the BeSt Age app, we also considered results from a systematic literature review performed by our group which examined the effectiveness and acceptability of e- and m-health interventions to promote physical activity and prevent falls in nursing homes [29].

As a fifth and last step, a cluster randomized controlled trial was designed and conducted to examine the effectiveness of the app with regard to different outcomes of interest.

To conclude, we developed the app in an iterative manner, i.e., the app was continuously revised and improved based on the several steps we took, to ensure that the final version would fulfill both expectations and needs of the users, i.e., nursing home staff and residents.

Features and functionality of the BeSt Age app

In general, as mentioned above, the purpose of the app is to assist nursing home staff in delivering individualized exercise training programs to small, homogenous groups of nursing home residents. Training with a single individual is also possible but less feasible given the restricted time and personnel resources in many care facilities [30]. A distinctive feature of the app is that it takes the cognitive and motor performance status of an individual into account, i.e., exercises that align with the motor and cognitive capabilities of the small group of residents are selected through a distinctively developed algorithm. To this end, the app

contains a large selection of about 150 different exercises and movements, and also different variations for most of them in terms of intensity and/ or motor requirements needed to perform the exercise, thereby allowing for maximal variety in the training. Furthermore, the app creates a detailed plan for each exercise session, thereby reducing the workload of staff for preparing and providing exercise sessions.

The app works as follows: Nursing home staff are first asked to create an overall profile for their facility (e.g., by providing the name and indicating which materials are available) as well as a personal profile for each resident, by inserting subjective information on motor (multiple selection: the person is able to get up from a chair with or without aids; person is able to walk with or without aids; the person is not able to get up from a chair or walk) and cognitive performance level (single selection: the person has no or little cognitive impairment; the person has moderate cognitive impairment; the person has severe cognitive impairment), as well as personal exercise preferences (multiple selection: person likes to dance/ exercise with music; person likes to sing; person likes to exercise with balls). Once the profiles for all residents are created, matching algorithms implemented in the app create small, homogeneous groups of residents (up to 7 persons) with similar motor and cognitive performance status as well as personal exercise preferences. To this end, residents' characteristics and interests are matched by the algorithm with the requirements defined for each exercise (e.g., the person must be able to stand for this exercise) and the materials available in the respective care facility. The app also features a calendar function which can be used by nursing home staff to plan and schedule exercise sessions with different groups of residents for the entire week, month or period of interest. On the day of a given exercise session, nursing home staff operate the tablet and will be guided step-by-step through the entire exercise training program by following the on-screen instructions. On the starting screen, they are first shown an overview of all exercises included in the entire session, as well as any materials (e.g., balls, chairs, balloons) that may be needed, so that they can prepare the materials in advance. Once the program is started, each exercise will be shown and described in detail on a new screen, containing information about the name and purpose of the current exercise, any material needed (e.g., chair), potential risks or side effects (e.g., pain), duration or number of repetitions (e.g., two times of 20 repetitions). A brief video clip showing an older person carrying out the exercise is also provided on the screen. Additionally, the exercise program is accompanied by background music that can be used if needed.

The main exercise program contains two to three exercises for warm-up (i.e., mobilization and coordinative exercises), five to seven main exercises (i.e., strength, balance, endurance und gross-motor coordination), and two exercises for cool-down (i.e., relaxation, body

perception), and takes approximately 25 to 30 minutes to complete. The algorithm is trained to provide well-balanced sessions, including a comparable number of exercises for strength of different body parts, mobility, and balance. If needed, nursing home staff can adapt the exercise sessions by skipping exercises while using the app (also, exercises can be removed or added before the program has been started on the app). After each session, nursing home staff can rate each exercise regarding the viability and vogue of attendees using a feedback feature. This feedback is then used to ensure progression with regard to intensity by suggesting more challenging versions of the exercises in upcoming sessions, if and when an exercise has been rated positively several times. If an exercise is rated poorly, the app will exclude it and similar exercises from further sessions for this group. Furthermore, attendance of all individuals by group can be documented after the session, with the option of choosing reasons for non-attending the program. Nursing home staff can also review the description of the upcoming session to identify any required materials and prepare them in advance. Of note, the app also features a gamification element for motivational purposes, i.e., the exercising group of nursing home residents is awarded credit points for completed sessions, which can be used to purchase new items (e.g., bench, flowers) for a digital nursing home garden. Please refer to the screenshots (figures 1-3) showcasing the main features of the app.

Implementation approach: Cluster randomized controlled trial

To test the effectiveness and acceptability of the BeSt Age app, we carried out a 12-week cRCT, i.e., randomization into an intervention group and control group was done at facility level in order to ensure a sufficient number of participants that would allow for the in-built matching algorithm to form homogenous groups for the exercise training program. To this end, a list of nursing homes in the city of Karlsruhe and the surrounding districts in the German state of Baden-Wuerttemberg was created and we contacted the nursing homes by telephone and provided on-site informational meetings. Allocation of nursing homes to either the intervention or control group was performed using a computer-generated randomization procedure. If possible, investigators assessing gait, motor, and cognitive performance outcomes were blinded to group allocation. Blinding of participants was not possible. The study adhered to the guidelines and recommendations outlined in the Consolidated Standards of Reporting Trials (CONSORT) statement [44, 45] as well as the CONSORT extension to cluster-randomized trials [46]. The study was preregistered in the German National Register of Clinical Trials (DRKS00032349), and ethical approval was obtained from the ethics committee of the Karlsruhe Institute of Technology, Karlsruhe, Germany.

Study sample

An a-priori power analysis was conducted using G*Power version 3.1.9.7 [47], based on the assumption that we would calculate two-factor ANOVAs with repeated measurements, two groups, two measurements, $\alpha = 0.05$, $1-\beta = 0.80$, $\eta^2 = 0.02$, and revealed a required total sample size of 100 participants. The effect size ($\eta^2=0.02$) used for the calculation of the required sample size was based on results presented in our literature review [29]. However, we will decide on the appropriate statistical approach based on the ICC derived from the original data once data collection is completed. In the literature, [48] an ICC of ≥ 0.05 has been suggested as a cutoff value for determining whether to use multi-level modelling.

Considering an estimated dropout rate of 20%, anticipated low adherence to the intervention, and adjustment to cluster-randomization using a variance inflation factor [49], the sample size was set to 255 participants. We defined the following inclusion criteria for nursing home residents: aged > 65 years; at least 50% functional capacity of extremities; and ability to follow verbal instructions. Exclusion criteria were very severe cognitive, neurological, or motor impairments or disorders. We deliberately did not formulate any additional exclusion criteria in an attempt to be rather inclusive, particularly since prior studies had defined more strict inclusion and exclusion criteria that may not apply to many residents of nursing homes and may not be reflective of a real-world scenario [29]. Eligibility of participants was verified at baseline assessment and based on the aforementioned pre-defined criteria. Written informed consent was obtained from all participants or, in case of participants unable to consent, their legal guardians prior to the study.

Intervention and outcome measures

The intervention group received a 12-week intervention with the BeSt Age app (including features as described above) in small, homogenous groups of about 5 to 7 participants, on average, with two exercise sessions per week, each lasting about 25-30 minutes. The control group received usual care. Baseline (T0) and post-intervention (T1) assessments were carried out, and a follow-up survey (T2) was conducted three months after the end of the intervention to assess fall incidence. Please refer to figure 4 for graphical display of the study design.

Primary outcomes of interest among participating nursing home residents included quality of life assessed using the 8-item EUROHIS-QOL questionnaire (calculated variable: total score ranging from 8 to 40 with a lower score indicating worse quality of life) [50, 51], and fall risk evaluated through two performance-oriented balance tests, i.e., the Timed Up and Go Test assessing lower extremity function and mobility (calculated variable: time in seconds to get

up from chair, walk 3 meters, turn around, return 3 meters and sit back down at chair; walking aids such as canes or rollators were permitted) [52] and the Berg Balance Scale assessing static and dynamic balance through a 14-item test battery, with each item rated from 0-4. Here, a lower score indicated greater balance impairment (calculated variable: total score ranging from 0 to 56) [53]. We also recorded fall incidence from nursing home staff at six months before the intervention, during the 12-week intervention period, and during the three-month follow-up period post-intervention. To this end, a fall was defined as “an event in which the individual unintentionally comes to rest on the ground or another lower level" according to the ‘Expert Standard for Fall Prevention in Nursing Care’ of the German Network for Quality Development in Nursing Care [54].

Secondary outcomes of the cluster randomized controlled trial included three motor performance tests, i.e., grip strength assessed using a digital hand dynamometer according to the Southampton-Protocol (calculated variable: best out of six trials, i.e., three for each hand, in kg) [55], a 30-seconds arm curl test (calculated variable: number of performed arm curls in 30 seconds) [56], and a 10-meter walking test (two trials at regular/ preferred pace; two trials at fast pace; walking aids such as canes or rollators were permitted) [57]. Additional outcomes included cognitive status assessed using the Montreal Cognitive Assessment (MoCA; calculated variable: score ranging from 0 to 30, with lower score indicating greater cognitive impairment) [58, 59], the end-state comfort effect as an indicator of anticipatory motor planning using the bar-transport-task (calculated variables: number/ percentage of end-state comfort trials in uncritical/ critical conditions) [60], activities of daily living assessed using the Katz-Index (calculated variable: score ranging from 0-6, with lower score indicating lower function and dependence) [61], life space/ physical activity behavior assessed using the Life-Space Assessment in Institutionalized Settings (LSA-IS; [62]) questionnaire (calculated variable: score ranging from 0 to 90 with a lower score indicating a greater degree of immobility) [63], and fear of falling assessed with the 7-item Short Falls Efficacy Scale-International (calculated variable: score ranging from 7 to 28 with higher score indicating more severe concern about falling) [64]. All participants also rated their digital competence, and we created a score ranging from 1 (very low) to 5 (very high). Additionally, participants were asked various questions, for example about their reasons and motivation to participate in physical activity programs prior to the intervention period. After the 12-week intervention, participants of the intervention group were asked whether they were motivated to continue with the BeSt Age program, and if the gamification element had influenced their motivation.

Assessments conducted among nursing home staff who delivered the physical exercise

interventions included but were not limited to usability assessed using the System Usability Scale (calculated variable: score ranging from 0-100 with higher score indicating better usability) [65], user experience using the AttrakDiff (calculated variables: pragmatic quality, hedonic quality divided into identity and stimulation, and attractiveness with scores ranging from -3–3) [66], affinity for technology and app usage statistics. These considerations were based on implications derived from the RE-AIM Framework (https://re-aim.org/; [67]) which assesses reach (engagement among nursing home residents), effectiveness (health outcomes), adoption (nursing home staff willingness), implementation (consistency of use), and maintenance (long-term sustainability). Furthermore, nursing home staff was asked open-ended questions about reasons for offering physical activity programs and motivation to work with the BeSt Age app prior to the intervention period. After the 12-week intervention, they were additionally asked whether they enjoyed working with the app and whether they were motivated to use the BeSt Age app in the long-term. Please refer to table 1 for an overview of all primary and secondary outcomes. For all assessments, we used German language versions.

RESULTS

Characteristics of participants (nursing home residents) at baseline

A total of 229 persons (171 females, 58 males; 137 intervention group, 92 control group) from 19 different nursing homes (11 intervention group, 8 control group) participated in the baseline assessment. Mean age (SD) was 85.4 (7.4) years, and participants rated their digital competency as low (mean score (SD), 1.9 (1.1)). The intervention group included a statistically significantly larger number of females, participants had a higher body mass index, and more participants rated attending physical activity programs as important. There were no additional statistically significant differences between intervention and control group at baseline. Four participants of the intervention group (3%) and three participants of the control group (3%) had a MoCA score of ≥ 26 indicating no cognitive impairment, while 40 participants of the intervention group (32%) and 33 participants of the control group (38%) had a score between 18 and 25, indicating mild cognitive impairment. Eighty-one participants of the intervention group (65%) and 51 participants of the control group (59%) had a score ≤ 17, indicating moderate to severe cognitive impairment. Of note, MoCA data were missing for 17 participants, since we did not calculate a MoCA score for participants with visual or motor impairments or when German was not the mother tongue. With regard to mobility, 24 participants of the intervention group (26%) and 21 participants of the control group (35%) took 19 seconds or less to complete the Timed Up and Go test, indicating no mobility

impairment, whereas 33 participants of the intervention group (36%) and 19 participants of the control group (32%) took between 20 and 29 seconds to complete indicating impaired mobility, and 35 participants of the intervention group (38%) and 20 participants of the control group (33%) took ≥ 30 seconds reflecting severe mobility impairment. Of note, 72 participants (33%) used no aid for performing the test, 82 used a walker (37%), and the remaining participants used other tools such as a walking stick, wheelchair or were unable to carry out the test. Ninety-seven participants of the intervention group (74%) and 66 of the control group (73%) had no falls 6 months prior to study baseline, 22 of the intervention group (17%) and 13 of the control group (14%) had one fall, and 12 participants of the intervention group (9%) and 11 of the control group (12%) had two or more falls. Please refer to table 2 for an overview of participants' characteristics, stratified by group allocation.

Selected results derived from nursing home staff at baseline

We included 37 nursing home staff with a mean (SD) age of 51.7 (11.5) years. 20 reported having a certification to deliver physical activity, and mean (SD) years of experience with delivering physical activity were 7.9 (7.2). Qualitative analyses on assessments conducted among nursing home staff revealed that the app was rated as very good based on the System Usability scale (mean (SD) score, 87 (15)), and was perceived as easy to administer, well designed, including a good selection of effective and varied exercises, and limiting the time for preparation of the physical exercise program delivery to a minimum. Suggestions for improvement were mentioned with regard to duration of exercises or breaks between exercises, and level of intensity and difficulty of exercises, amongst others.

DISCUSSION

The novel, innovative BeSt Age app has been developed and implemented in a cluster randomized controlled trial among 229 older adults residing in 19 nursing homes in Germany. The app offers a unique approach to deliver physical exercise in nursing homes. It contains a comprehensive exercise library and uses an in-built algorithm to select appropriate exercises. This selection process considers residents' current motor and cognitive performance status, as well as their exercise preferences. Using the app, nursing home staff, regardless of their knowledge of physical exercise training, are enabled to deliver an individualized exercise program to nursing home residents. Of note, no or only minimal preparation is needed, and we deliberately designed the app to keep burden for staff low.

Results on the effectiveness of the BeSt Age app for nursing home residents, including but not limited to falls and fall-related outcomes, motor performance and activities of daily living,

as well as quality of life will become available in the near future. Upon demonstrating effectiveness, we plan to implement the app across German nursing homes. It is conceivable that the BeSt Age app may be scaled up beyond a nursing home setting, to be also used in community-based senior centers, rehabilitation programs, or independent living facilities. Collaboration with health insurance providers and policymakers could further facilitate app adoption, for example as a reimbursable intervention for fall prevention and mobility improvement. We may also provide an English version of the app to facilitate future use in research and practice on an international scale.

Conclusion

The BeSt Age app may be one viable solution for addressing the intention-behavior gap related to physical activity among older adults. While many nursing home residents recognize the benefits of exercise, most older adults fail to meet recommended physical activity levels and various barriers prevent them from engaging, including but not limited to lack of motivation or inadequate staff resources. Our app may help in bridging the intention-behavior gap by incorporating behavior change techniques (e.g., goal setting, feedback mechanisms, and positive reinforcement through gamification), thereby possibly increasing adherence to physical activity routines. This may also have various implications for clinical practice. Furthermore, many countries face nursing home staff shortages, and our app may be highly valuable in nursing homes, as it can support nursing home staff in delivering exercise training to residents without adding additional workload or requiring specific resources. Thus, we postulate that the app may be used to promote physical activity and prevent falls in nursing home residents, thereby ultimately contributing to maintaining quality of life and overall well-being in this vulnerable population. Finally, many older adults face challenges in using digital interventions. By designing the app to be intuitive and staff-assisted, the BeSt Age app overcomes digital literacy barriers, ensuring accessibility for residents with or without cognitive impairments. Future directions may include investigation of the long-term adherence to our digital exercise program, exploration of the role of gamification in sustained motivation, and conduct of comparative studies with other digital interventions to assess relative effectiveness.

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ABBREVIATIONS

ANOVA = Analysis of variance
CG = Control group
COM-B = Capability, Opportunity, Motivation and Behavior
CONSORT = Consolidated Standards of Reporting Trials
cRCT = Cluster randomized controlled trial
EUROHIS-QOL = European Health Interview Survey-Quality of Life
ICC = Intraclass correlation coefficient
IG = Intervention group
InCoPE = Individualized Cognitive and Physical Exercise
Kg = Kilograms
LSA-IS = Life-Space Assessment in Institutionalized Settings
MoCA = Montreal Cognitive Assessment
RE-AIM = Reach, Effectiveness, Adoption, Implementation, Maintenance
SD = standard deviation

DATA AVAILABILITY

The datasets generated during this study may be made available by the principal investigators upon reasonable request.

CONFLICTS OF INTEREST

None declared.

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Table 1: Overview of primary and secondary outcomes

Dimension	Assessment	Time of measurement			Calculated variable or score used for analysis
		T_0	T_1	T_2	
Primary outcomes					
Quality of life	EUROHIS-QOL questionnaire [50, 51]	NHR	NHR		Total score (8-40)
Fall risk (performance-oriented balance tests)	Timed Up and Go [52]	NHR	NHR		Time in sec
	Berg Balance Scale [53]	NHR	NHR		Total Score (0-56)
Falls	Fall incidence [54]	NHR	NHR	NHR	Number of falls
Secondary outcomes					
Grip strength	Digital hand dynamometer [55]	NHR	NHR		Best out of 6 trials in kg
Arm strength	30-seconds arm curl test [56]	NHR	NHR		Number of arm curls in 30 sec
Walking speed	10-meter walking test [57]	NHR	NHR		m/s
Cognitive status	Montreal Cognitive Assessment [58, 59]	NHR	NHR		Total score (0-30)
Anticipatory motor planning	Bar-transport task [60]	NHR	NHR		Number/ percentage of end-state comfort grasps
Activities of daily living	KATZ Index [61]	NHR	NHR		Total score (0-6)
Life Space / Physical activity behavior	Life-Space Assessment in Institutionalized Settings (LSA-IS) [62, 63]	NHR	NHR		Total score (0-90)
Fear of falling	7-item Short Falls Efficacy Scale-International [64]	NHR	NHR		Total score (7-28)
Digital Competence	Single-item (Likert-Scale format)	NHR	NHR		Total score (1-5)
Reasons for and motivation to participate in physical activity in general	Open-ended questions	NHR			-
Motivation to continue using BeSt Age app	Open-ended questions		NHR		-
Influence of gamification	Open-ended questions		NHR		-
Reasons and motivation to work with BeSt Age app	Open-ended questions	NHS			-
Usability of BeSt Age app	System Usability Scale [65]		NHS		Total score (0-100)
User experience	AttrakDiff [66]		NHS		4 dimensions

					scored -3 – 3
App usage	User statistics derived from app data		NHS		-
Enjoyment	Open-ended questions		NHS		-
Future app use	Open-ended question		NHS		-

Abbreviations: EUROHIS-QOL = European Health Interview Survey-Quality of Life, NHR= nursing home residents, NHS= nursing home staff

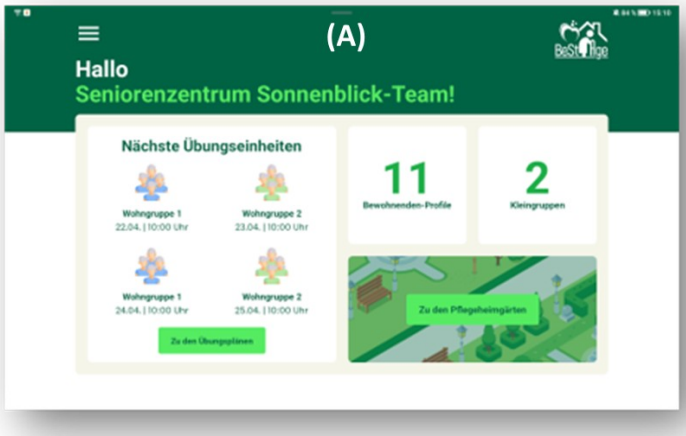
Table 2: Participant characteristics (nursing home residents) at baseline

Variable	Intervention group (N = 137)	Control group (N = 92)	Total (N = 229)	p
Female sex, N (%)	111 (81.0)	60 (65.2)	171 (74.7)	<.01
Age in years	85.0 (7.6)[2]	85.9 (7.2)	85.4 (7.4)	.31§
School education, N (%)				.14
No school leaving certificate	13 (10.1)[8]	3 (3.3)[3]	16 (7.3)[11]	
Basic secondary school-leaving certificate	71 (55.0)[8]	53 (59.6)[3]	124 (56.9)[11]	
Intermediate secondary school-leaving certificate	29 (22.5)[8]	16 (18.0)[3]	45 (20.6)[11]	
Higher education entrance qualification (A-levels)	16 (12.4)[8]	17 (19.1)[3]	33 (15.1)[11]	
Body mass index (kg/m^2)	28.1 (5.8)[8]	25.9 (5.0)[5]	27.2 (5.6)[13]	.02§
Digital competence score	1.9 (1.1)[3]	1.8 (1.2)	1.9 (1.1)[3]	.43§
Quality of life and cognition				
EUROHIS-Quality of life score	30.5 (4.0)[8]	29.9 (4.2)[1]	30.3 (4.1)[9]	.43§
Montreal Cognitive Assessment score	13.9 (6.6)[12]	15.1 (7.1)[5]	14.4 (6.8)[17]	.18§
Motor performance assessments				
Timed up and go test (time in sec)	27.6 (11.7)[44]	28.3 (16.5)[29]	27.9 (13.8)[73]	.53§
Grip strength (in kg)	17.5 (6.7)[7]	18.4 (8.7)	17.9 (7.6)[7]	.87§
10m walking test (in m/sec) at regular/ preferred pace	0.61 (0.25)[25]	0.58 (0.26)[10]	0.60 (0.25)[35]	.37#
Armcurl (number of curls in 30 sec)	7.6 (4.5)[23]	8.5 (5.8)[1]	8.0 (5.1)[24]	.23§
Berg Balance Scale score	26.5 (16.3)[11]	28.3 (16.0)[2]	27.2 (16.2)[13]	.41§
Short Falls Efficacy Scale score	11.6 (4.5)[12]	11.4 (4.2)[1]	11.5 (4.4)[13]	.75§
Number of falls (6 months before baseline)	0.54 (1.46)[6]	0.60 (1.62)[2]	0.57 (1.52)[8]	.85§
Physical activity behavior and activities of daily living				
Life-Space Assessment in Institutionalized Settings score (participant-completed)	23.5 (14.7)[3]	23.4 (13.0)	10.5 (5.2)[3]	.77§
Life-Space Assessment in Institutionalized Settings score (nurse-completed)	28.1 (14.5)[6]	29.2 (18.1)[13]	28.6 (15.9)[19]	.74§
Katz index	3.7 (2.0)[13]	4.0 (2.0)[11]	3.8 (2.0)[24]	.26§
Questions on physical activity				
Is it important for you to attend physical activity programs? N (%)				<.01
Yes	120 (88.9)[2]	63 (70.0)[2]	183 (81.3)[4]	
No	15 (11.1)[2]	27 (30.0)[2]	42 (18.7)[4]	
Are you motivated to attend the Best Age intervention? N (%)				-
Yes	84 (62.7)[3]	-	-	
No	18 (13.4)[3]	-	-	

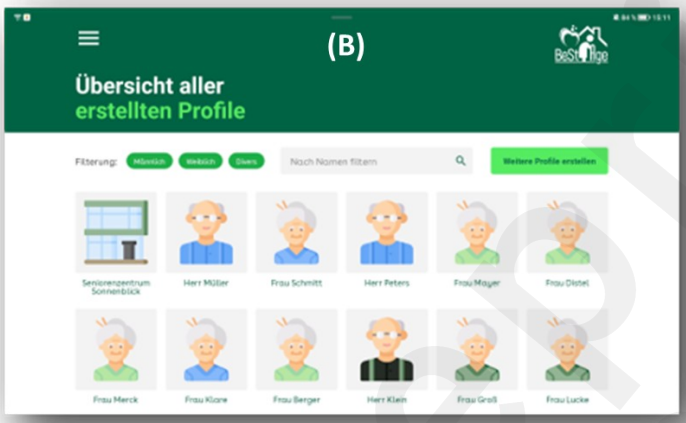
Undecided	32 (23.9)[3]	-	-	
Did you participate in physical activity before the study? N (%)				.07
Yes	119 (90.2)[5]	66 (81.5)[11]	185 (86.9)[16]	
No	13 (9.8)[5]	15 (18.5)[11]	28 (13.1)[16]	

Values are means and standard deviations unless indicated otherwise. [N] indicates number of participants with missing information. p calculated using chi-square test (for categorical data) or Mann-Whitney U test[§] (for continuous, nonparametric data) or t-test[#] (for continuous, normally distributed data). All percentages computed relative to the sample with valid data (missing persons not included). Digital competence score: possible range 1-5, lower score indicates lower competence. EUROHIS-Quality of life score: possible range 8-40, lower score indicates worse quality of life. Montreal Cognitive Assessment score: possible range 0-30, lower score indicates more severe cognitive impairment; persons with visual or motor impairments or for whom German was not the mother tongue were not considered. Berg Balance Scale score: possible range 0-56, lower score indicates greater balance impairment. Short Falls Efficacy Scale score: possible range: 7-28, higher score indicates more severe concern about falling. Life-Space Assessment in Institutionalized Settings score: possible range 0-90, lower score indicates greater degree of immobility. Katz index: possible range 0-6, lower score indicates lower function and dependence.

Figure 1: Profiles of facilities and individuals

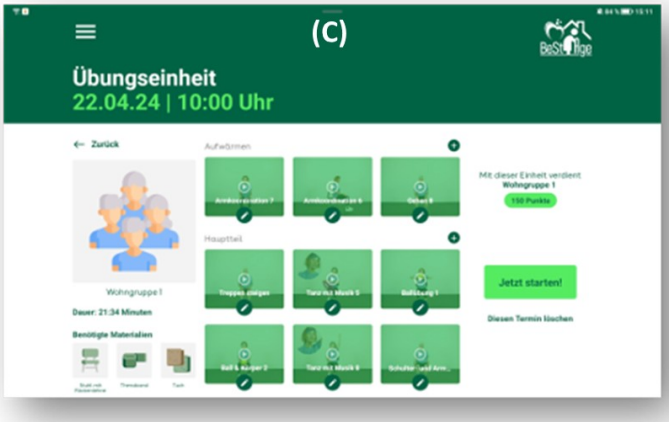


(A) Overall facility profile showing an overview of participants, training groups, and date and time of the next training sessions.

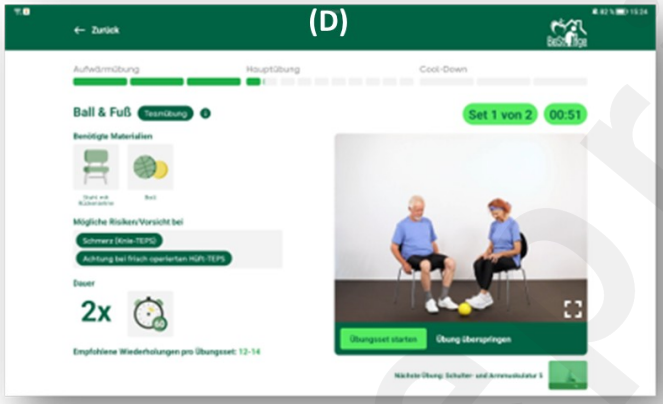


(B) Overview of individual profiles of the participants with intergrated search and filter function.

Figure 2: Training sessions



(C) Overview of a training session including participants, duration of the session, material needed, and planned exercises.

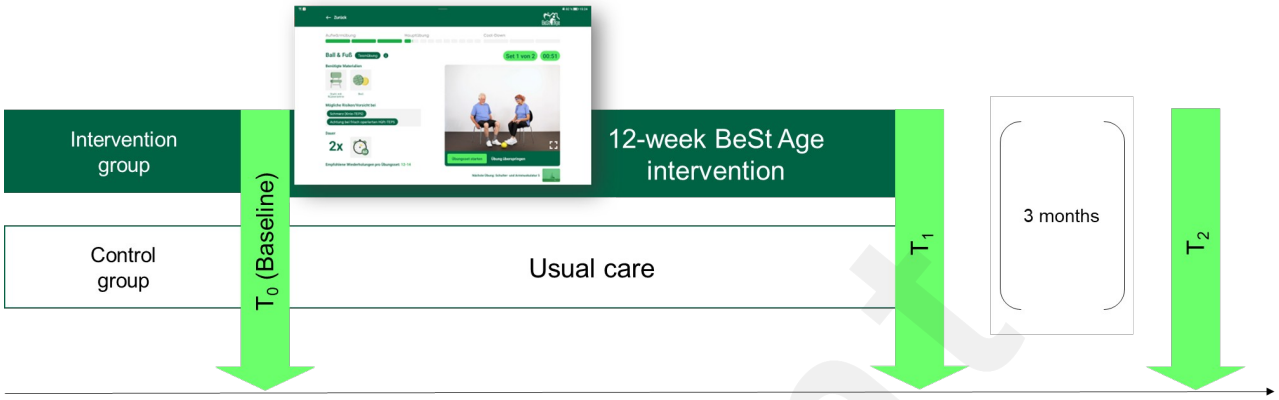


(D) Exercise screen which includes material needed, possible risks, duration of the exercise, suggested repetitions, and a video of the exercise execution.

Figure 3: Gamification within the BeSt Age app

(E) Nursing home garden as gamification element.

Figure 4: Study design

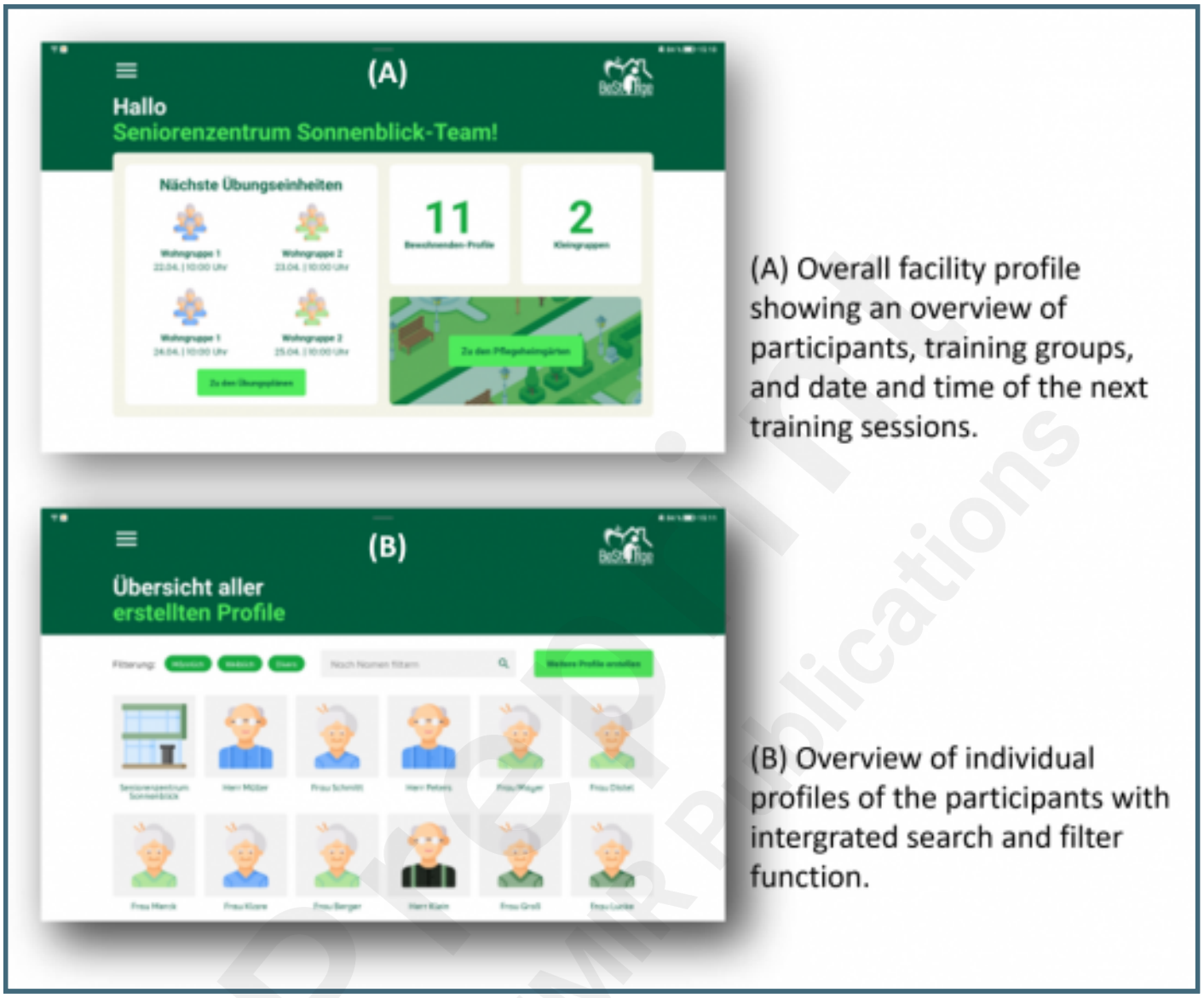


Please refer to table 1 for an overview of all primary and secondary outcomes assessed at T_0, T_1, and T_2.

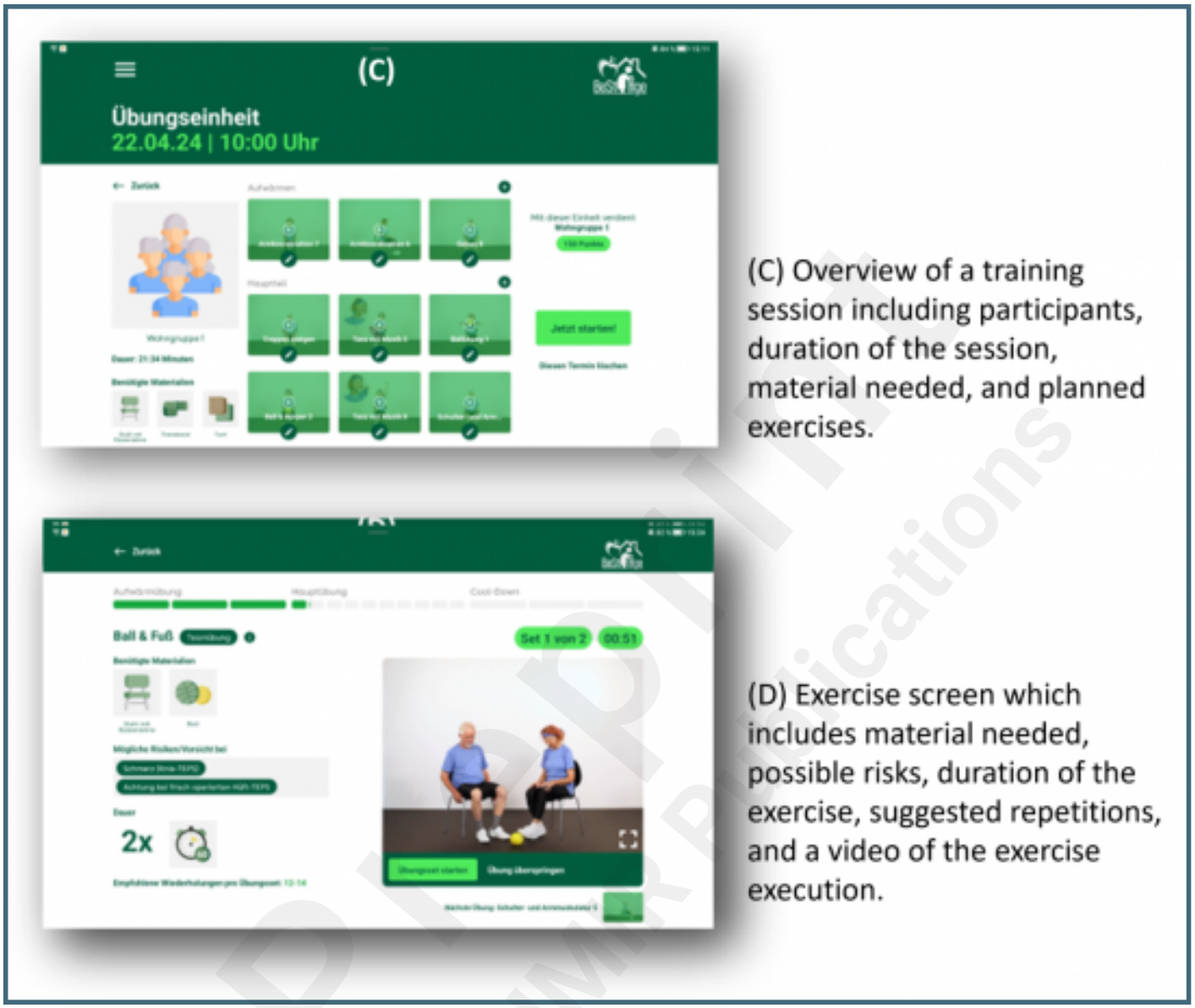
Supplementary Files

Figures

Profiles of facilities and individuals.



Training sessions.



Gamification within the BeSt Age app.

Study design.