Original Paper

Development and Feasibility of the Bern Brain Training App for Older Adults With Subjective Cognitive Decline and Mild Cognitive Impairment: Secondary Analysis of a Randomized Controlled Trial

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Abstract

Background: Computerized cognitive training (CCT) aims to mitigate cognitive decline in subjective cognitive decline (SCD) and mild cognitive impairment (MCI). However, adherence and long-term engagement remain challenging in remote CCT interventions.

Objective: Describe the development and design of the Bern Brain Training (BBT), a tablet-based app to remotely train cognitive functions and assess its feasibility, usability, and acceptability. This is a secondary analysis of a previously published randomized controlled trial (RCT).

Methods: Unity Game Engine and C# programming were used to design 16 games targeting episodic, semantic, and working memory, and spatial abilities. We assessed feasibility, usability, and acceptability of the BBT (50 sessions in 10 weeks, each 24 minutes) in 116 participants with subjective cognitive decline (SCD, n=89) or mild cognitive impairment (MCI, n=27). One session per week was played in-clinic in a group setting of 4-6 participants. Within the main RCT with parallel groups, participants were pseudo-randomized to one of three groups, with an allocation ratio of 1:1:1. The BBT was administered in all three treatment groups at different time points. Group 1 (n=36, 31%) started with the BBT (10 weeks); Group 2 (n=34, 29%) started with active control training (10 weeks), and then moved on to the BBT (10 weeks); Group 3 (n=46, 39%) started with the BBT (10 weeks) after a waiting period of 10 weeks.

Results: Feasibility was high (adherence rate: mean 5.10, SD 0.69 BBT sessions/week; weekly group sessions: mean 9.18 SD 1.05; concluded BBT sessions: 5891, 91%). On a 7-point Likert scale, participants showed high motivation across cognitive domains and training groups (mean 6.15, SD 1.05), and groups did not differ significantly in adherence (P>.05). Usability was good with 61 (0.94%) help button presses recorded across 6489 sessions played. Acceptability (7-point Likert scale) was satisfying in game experience ratings of entertainment (mean 5.43, SD 1.39), with low frustration rates (mean 3.01, SD 1.79), despite the BBT being perceived as challenging (mean 5.52, SD 1.22). The games were perceived as most efficient in training memory (mean 5.7, SD 1.20) and thinking abilities (mean 5.43, SD 1.18). SCD and MCI did not differ significantly in game experience and perceived game efficacy (P>.05).

Conclusions: The BBT demonstrated high feasibility, usability, and acceptability. Its innovation lies in the participatory and professional game design, task diversity, adaptivity, and social elements, with a large sample size that sets it apart from other studies. These findings advance the field by demonstrating that tablet-based, remote cognitive training is feasible and well accepted in older adults with cognitive impairment, emphasizing the importance of these parameters for high training adherence and supporting its potential integration into clinical practice. Future research should extend evaluation to care-home settings and populations with more advanced cognitive impairment.

Trial Registration: clinicaltrials.gov NCT04452864; https://clinicaltrials.gov/study/NCT04452864

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Keywords: tablet-based; cognitive training; app; remote; multidomain; feasibility; usability; acceptability; subjective cognitive decline; mild cognitive impairment; older adults; dementia; neurodegenerative disorders

Introduction

Nonpharmacological prevention and treatment options, such as computerized cognitive training (CCT), are vital in counteracting cognitive decline in neurodegenerative disorders. CCT is used to target cognitive functions typically affected in the course of subjective cognitive decline (SCD) and mild cognitive impairment (MCI), including episodic memory, spatial abilities, semantic memory, and executive functions [1,2]. Multidomain CCT appears to be particularly effective, with some studies reporting long-lasting cognitive improvements and far transfer effects to everyday functioning and activities of daily living in healthy older adults [3]. Positive effects of CCT on memory, executive functions, and activities of daily living have been shown in individuals with SCD [4], MCI [5], and Alzheimer disease (AD) [6,7].

Remote administration of CCT is an important avenue to follow given the rise in the adoption of digital technologies by older adults. Alone in the past few years, internet use in European adults between 65-74 years has risen from 57% in 2019 to 67% in 2022 [8]. In the United States, 79% of those 65 years and older report being internet users, and 44% are tablet owners [9]. We can leverage this shift in digital engagement to move towards home-based treatment options as technology becomes more pervasive and accessible. Remote administration of CCT (eg, using tablets and smartphones) offers advantages in terms of convenience and accessibility, allowing individuals to engage in training activities in their home settings. Remote administration enables longer training durations and higher frequency, while keeping costs low and facilitating the inclusion of underserved populations.

However, adherence and long-term engagement can be challenging, as some individuals may have difficulty using the technology or maintaining motivation over time. Several factors have been singled out as predictors of adherence: (1) Feasibility: familiarity with the device is vital for reaching high levels of adherence [10], which in turn results in larger benefits; (2) Adaptivity: tailoring the CCT to the needs of the population increases adherence, which can be further supported with rewards during the game [11]. CCTs developed for patient populations often offer a restricted set of games with unappealing designs and limited adaptivity, which can result in reduced motivation and adherence. Individually adapted levels of difficulty are important to maximize the efficacy of a CCT, as a "mismatch" between task demands and performance level is key to neuroplasticity [12]; (3) Quality: the motivation to repeatedly play a set of games demands an enjoyable game experience, which can be reduced by software issues or low-quality visuals [13]. Despite the growing number of remote and tablet-based CCT programs, several gaps remain in existing literature. Many programs are developed with limited public involvement of the intended end users, although participatory design may be particularly important for older adults and individuals with cognitive impairment to ensure usability, accessibility, and sustained engagement [14]. Furthermore, existing CCT studies often rely on relatively small samples and short training periods, limiting conclusions about feasibility and long-term adherence [15].

Building on these considerations, our objective was to develop and design the Bern Brain Training (BBT) app, a tablet-based CCT for individuals with SCD and MCI, and assess its feasibility, usability, and acceptability. The BBT was developed to address these gaps by involving end users in the co-design process, enabling independent home-based training with detailed instruction on a tablet with accessible touch interaction, adapting task difficulty to individual performance, and combining a variety of exercises that challenge multiple cognitive as well as visual functions. The BBT also draws on principles from commercial games to create a more enjoyable, motivating, and less clinical training experience while still targeting cognitive domains relevant to SCD and MCI. Here, we present the secondary analysis of a randomized controlled trial (RCT), for which the BBT was developed and the efficacy results published [16]. The BBT is designed to target key cognitive domains affected by age- and disease-related cognitive decline. Our objectives within this secondary analysis were to (1) evaluate the feasibility, usability, and acceptability across the study population from a 10-week daily training program [16,17] and (2) to assess participants' perception of the app's effectiveness in improving cognitive performance.

Methods

Eligibility Criteria and Randomization

Participants reporting SCD or with objective cognitive impairment were screened and categorized as SCD or MCI participants based on existing diagnosis from the Memory

Clinic Bern or, if no established clinical diagnosis was available, on predefined Montreal Cognitive Assessment (MoCA) cutoff scores (SCD: MoCA>25, MCI: MoCA between 18 and 25). MoCA scores below 18, indicating dementia, were not included in the current analysis to avoid bias caused by stronger cognitive impairment. Participants were recruited in the larger Bern and Lucerne area from October 2020 until February 2023 (last follow-up in November 2023). Recruitment sources were the respective Memory Clinics and local newspapers. They were included according to the following criteria: (1) ability to give written informed consent, (2) aged 60-85 years, (3) native or fluent in German, (4) normal or corrected to normal vision and hearing, (5) ability to visit the study location, (6) MoCa >=18 [18]. Digital literacy was not an inclusion criterion. Exclusion criteria included substance abuse and severe medical conditions. The study adhered to the CONSORT (Consolidated Standards of Reporting Trials) guidelines (Checklist 1 and 2), and participants were pseudorandomized to one of three study arms (training, active control, or waitlist group) based on a stratified Mahalanobis distribution. Stratification was based on cognitive impairment level (Cognitive Telephone Screening Instrument, COGTEL [19]), age, and sex. The COGTEL was selected as the cognitive stratification factor due to its ability to provide a more comprehensive screening of memory and executive function compared to the MoCA. Pseudorandomization was chosen as it continuously adjusts probabilities to balance groups across stratification factors, ensuring well-matched baseline characteristics across study arms. By minimizing imbalances, it effectively reduces the risk of potentially confounding effects. Participants, investigators, and outcome assessors were blinded to group allocations. The first participant was enrolled on October 1, 2020.

Ethical Considerations

This concluded study was registered prospectively on July 1, 2020 (NCT04452864). The study was approved by the local Ethics Committees (Kantonale Ethikkommission für die Forschung, Kanton Bern; Ethikkommission Nordwest- und Zentralschweiz, ID: 2020-00630) and was conducted in accordance with the Declaration of Helsinki. The methodology of the protocol follows the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines. Written informed consent was obtained from all participants for the original study, and the ethics approval covers the present secondary analysis without requiring additional consent. All participant data were pseudonymized prior to analysis; no directly identifying information was retained in the study dataset. Participants received no financial compensation for their participation. No individuals are depicted nor can be identified in any images or Multimedia Appendices included in this manuscript.

Study Design

The study design is summarized here, while additional methodological details and outcomes of the standard RCT have been reported in [16]. The protocol and statistical analysis plan can be accessed (Checklist 3, Template for Intervention Description and Replication intervention description) [17]. The bicentric (Memory Clinics Bern and Lucerne) RCT with parallel groups included 3 study arms (BBT, active control, and waitlist group). In total, we assessed 116 participants with SCD (n=89) or MCI (n=27). All participants received an Apple iPad and played with the BBT daily for 10 weeks (50 sessions, each 24 minutes, playing 3 games), including weekly in-clinic group sessions. Four sessions per week were played at home, and one session was played in the weekly group sessions (4-6 participants). Participants were moreover allowed to play an additional bonus session per week (which results in max. 6 sessions/week). The intervention group started with the BBT immediately, the waitlist group started with a delay of 10 weeks, and the active control group first underwent 10 weeks of active control training (unspecific cognitive activity) before subsequently starting the BBT [16,17].

In the weekly group sessions, participants played the training session of the day with new games being introduced gradually. Two games were available immediately within the first week, with 2 new games being added every subsequent week. The in-person group sessions were led by neuropsychologists and research assistants and served the purpose of increasing adherence due to the social aspect and interactions, and as a possibility to discuss technical issues and BBT-related challenges experienced during the previous week. This was complemented by feedback from the game experience questionnaires (paper-pencil). At home, the participants were encouraged to play on their own and had the option to press the help button for immediate technical support whenever needed. The active control group followed the same intervention matched for duration and frequency, but watched documentaries (24 minutes per session, 4 times a week) instead of playing the BBT. Documentaries were accessed within the BBT app using the same devices later employed for the BBT intervention. In weekly on-site group sessions, active control participants discussed documentary content, resolved technical issues, completed paper-pencil feedback questionnaires, and engaged in noncognitively demanding games, such as slow-speed Bingo, to maintain engagement without specific cognitive training. These activities ensured comparable social interaction and attentional engagement across groups, isolating the specific effects of the cognitive training intervention.

The inclusion of a waitlist control group allowed for the evaluation of natural changes over time (eg, practice effects or cognitive changes unrelated to the intervention), while staggering the intervention optimized resource allocation. Ethically, providing the BBT to all participants was essential, as it was hypothesized to have positive effects on cognition.

Before and after the intervention, participants underwent a comprehensive neuropsychological assessment including the MoCA for general cognitive abilities, the Auditory Verbal Learning Test (AVLT) assessing episodic memory [20], verbal fluency, semantic memory (Graded Naming Test [21]), visuospatial skills (Rey-Osterrieth Complex Figure Test [22]), and short-term and working memory (digit span test forward and backward) [16].

Before each session, participants were asked to rate their current well-being and training motivation. After each session, they rated their play performance (7-point Likert scale and in-game questionnaires, Multimedia Appendix 1). After 10 weeks, participants reported on their "subjective improvement in cognition" and the likelihood of "recommending the BBT to a friend" (9-point Likert scale; Multimedia Appendix 1, Checklist 2). Furthermore, we assessed the "desired training duration" (Multimedia Appendix 1) and recorded the number of help button presses and possible side effects. Game experience (frustrating, difficult, entertaining, challenging, and motivating) and perceived game efficacy (vision, everyday activities, multitasking, hand-eye coordination, reaction time, thinking abilities, and memory) questionnaires were completed one week after game introduction using a 7-point Likert scale (Multimedia Appendix 1).

The BBT App

The BBT (Table 1 and Multimedia Appendix 2) targets cognitive functions affected early in the course of cognitive decline (episodic memory, spatial abilities, semantic memory, and working memory). The inclusion of games to train working memory is thought to increase the likelihood of transfer of training benefits to untrained domains [23]. Four adaptive games were designed for the identified cognitive domains, resulting in 16 games. The app is tablet-based, and the games were played in a pseudorandomized order in each session, ensuring sufficient variability of trained domains and equal training durations of all games across the study population.

Table 1. Game descriptions of the 16 BBT[a] games per cognitive domain trained (episodic memory, spatial abilities, semantic memory, and working memory). Pictures for the Famous Faces game came from (copyright free) [24]; pictures for the "What's my name?" game were computer-generated faces from the "This person does not exist" website [25].

Domain and BBT game	Description
Episodic memory	
Shopping basket	Remember groceries presented on a belt. Inspired by [26].
Billboards	Remember the sequence of billboards. Inspired by [27].
What's my name?	Learn and remember face-name associations. Based on [28,29].
Artificial language learning	Learn Elvish vocabulary.
Semantic Memory	
Word grid	Find the name of a displayed object in a letter grid. Inspired by naming tasks (eg, [30]).
Pun game	Find a picture and a word that form a word pair.
Famous faces	Answer the question who the famous person in the picture is.
Wheel of Fortune	Participate in a game show and guess the correct word or phrase.
Spatial abilities	
Mental map	Move the animal to the correct position in a grid according to a reference object after movements along 3 axes.
Magic camera	Select the correct picture of a table that a camera would make. Inspired by [27].
Mansion	Navigate through a mansion and remember where you found the keys. Inspired by [31].
Wine cellar	Walk through a cellar and find your avatar after being shown the way. Based on [31].
Working memory	
Memory bears	Remember the sequence in which the bears were glowing and tap on them in reverse order. Based on the Corsi block backwards test [32].
Animal park	While indicating the orientation of several animals, their sequence and position have to be learned. Based on [33].
Safari	Take a picture of an animal according to the current n-back condition. Inspired by [34].
Quiz game	Answer quiz questions and remember the sequence of answers. Inspired by [28].

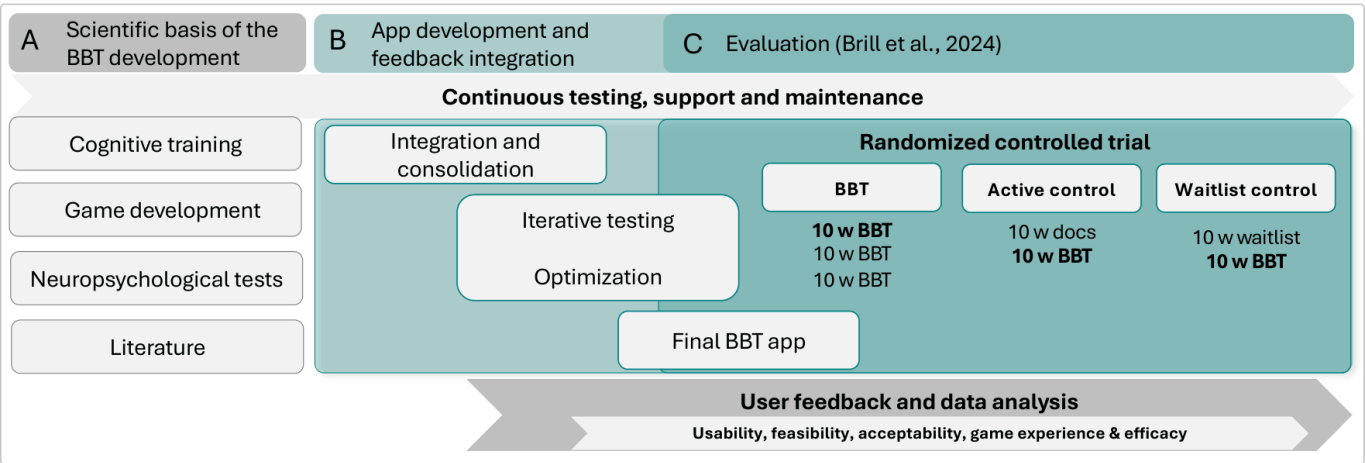
[a]BBT: Bern Brain Training.

Contributors and Development Background

The BBT was designed for a multicenter study [17]. The development started in 2019 with the first set of games finished by December 2020 and final versions by February 2022. A multidisciplinary panel with experience in neuropsychology and old age psychiatry, including neuropsychologists, psychologists, a game programmer, an occupational therapist, and a psychiatrist, selected and designed the games based on their experience and existing literature in regular meetings. The design was furthermore guided by input from experts in the field and participants, which is key to maximizing feasibility, usability, and acceptability [35]. For some games, cooperations allowed us to build on previous work. Pilot versions served to refine and optimize the gameplay experience and were presented to healthy older adults and to patients from the in-house memory training groups in Bern and Lucerne. In addition, feedback was given weekly by participants, leading to intermediate game versions. The feedback covered game experience in general, appropriateness of difficulty levels and adaptivity, usability (eg, speech recognition), and the presence of software bugs. This allowed us to integrate feedback from all potential end users and to

improve the app continuously during an iterative process. The BBT was designed to allow translations to other languages with little effort. The development and study pipeline is depicted in Figure 1.

Figure 1. Development and evaluation of the Bern Brain Training (BBT). Development phase A: first phase of BBT development based on scientific evidence; development phase B: iterative optimization process of the BBT development, including feedback integration from public involvement. The app development was finalized during the first part of the randomized controlled trial; evaluation phase C: effectiveness was evaluated in three randomized groups (reported in [16]). Usability, feasibility, acceptability, and user experiences were investigated in a secondary analysis across the 3 treatment groups, as all groups played the BBT at different time points. The first group started with the BBT (BBT only), the second group started with active control training (10 weeks) and then moved on to the BBT (active control and BBT), and the third group started with the BBT after a waiting period of 10 weeks (waitlist control and BBT) [16]. BBT: Bern Brain Training.



App Development

The BBT app was developed for the iPad using the Unity game engine version 2021.3 (Unity Software Inc) and coded in C# using Visual Studio (Microsoft). Art and music assets used within the app have come from a variety of places, including the Unity Asset Store (Synty Studios). Pictures for the Famous Faces game came from [24] (copyright free); pictures for the What's my name? game were computer-generated faces from the This person doesn't exist website [25] (copyright free). Procreate (Savage Interactive), Photoshop (Adobe Inc.), and Blender (Blender Foundation) were used to create several in-app assets. To track adherence in real time, we used an API call to a Google Form, which updated information on which games were played on which devices. In case adherence was not met (less than 3 sessions per week), participants were contacted by the investigator via calls or reminder emails. To improve access to the data, as well as control certain features remotely, a secure API to an in-house server was developed to track and record data in real time from participants' devices.

Setup and Sessions

A password-protected intuitive interface was developed where a pseudonymous ID and start date can be entered, and a "Pod ID" for keeping track of groups of participants. Games are depicted as islands on a map-styled menu on the home screen, with the 3 games to be played in the current session being highlighted, while the other games are hidden in the mist (Figure S1 in Multimedia Appendix 2). The player selects an avatar at the start of the training, which travels on a boat to the selected game island and is included in visuals throughout the games.

Distribution of the games was predefined as a cyclical sequence to balance game distribution and reduce confounding effects on training outcomes from the order or timing of game rollout. Difficulty of the games adapted to individual participant performance. This adaptivity varied from game to game based on the challenges specific to each game as well as user feedback. In general, it would require 2 wins in a row to advance in difficulty, and one loss to fall back, thus resulting in an equilibrium of difficulty with a higher win ratio for motivation. On completing a session, the participants unlock a shared puzzle piece, which corresponds to their color within their pod. This enables them to get feedback and see their pod members completing games in a collaborative way.

Guest Account

Each iPad also included a guest account. This was designed to allow participants to allow friends and family members to experience the games without affecting the play time, scores, or difficulty levels of the main account. Guest accounts allow for all games available to the participant to be played in an unlocked fashion.

Assisted Help Features

From within the main menu, participants could tap a "Help" button, which sent an email to the instructors, who would then get in contact with the participants for support. This allows for easy and fast access to technical support or help with game instructions. A teleconferencing button opens the teleconferencing app Zoom (Zoom Communications, Inc) with a predefined meeting room for extra support. The Zoom feature was added specifically to deal with the challenges imposed by the COVID-19 pandemic.

In-Game Data Collection

In-game data collection can be broken down into several components: (1) Real-time adherence data includes a limited amount of data that is uploaded to a Google Form to tell us which games were being played on which devices. This is useful for tracking adherence. (2) Debug data was recorded to store limited data to aid in debugging issues with the devices and the app, which enabled us to provide quick and remote fixes and solutions. Debug data is stored locally on the device, as well as emailed in a limited capacity to the app developer. (3) Profile data tracked an overview of the user's progress. Profile data is used by the app to control sessions and difficulty levels of each game, and a snapshot of the profile is recorded at the end of each round played in any game as a useful reference. (4) Unique game data is a game-specific data output file, which contains a unique set of rules and values, as well as the outcome of each round, so that conclusions can be drawn specific to each game's unique play style. Profile and unique game data are both stored physically on the device for retrieval at the end. To maintain control and flexibility of the app on each device remotely, a mobile device management tool was installed on each iPad. One major limitation is that iPads need to be collected for manual data removal at the end, and lost or damaged iPads could result in lost data.

Data Protection

Detailed performance data and debug logs are stored locally on the device and need to be manually extracted by plugging the tablet into a computer. A limited subset of adherence is stored online for the use of tracking whether patients are completing their tasks and to allow clinicians to follow up on missed sessions. A limited amount of debug data was emailed to a chosen email account to aid in bug fixes and support; however, this feature can be disabled. This ensures that important data is closed off from outside vectors, while basic information is still available to allow for limited support.

Data Analysis

The data were analyzed using the statistical program R Studio (Posit PBC) v2023.3.0.386. Descriptive statistics on demographic details, feasibility, and acceptability are reported. The primary interest was to analyze data across the three treatment groups, for which we performed one-way ANOVAs. As an exploratory analysis to examine differences between groups in in-game ratings over the course of training, we fitted separate linear mixed models for play performance, motivation, and well-being (7-point Likert scales), with group (BBT, waitlist, and active control), session number, and their interaction as fixed effects, and a random intercept for participant to account for repeated measurements. Models were estimated using restricted maximum likelihood, and *P* values for fixed effects were obtained using the Satterthwaite approximation for degrees of freedom. Further ANOVAs across all treatment groups were performed to elucidate the differences between the trained cognitive domains in terms of game experience (frustrating, difficult, entertaining, challenging, and motivating) and perceived game efficacy (vision, everyday activities, multitasking, hand-eye coordination, reaction time, thinking abilities, and memory) as dependent variables and the games as independent variables. Additional ANOVAs were performed to assess treatment group differences in game experience and perceived game efficacy. Tukey Honestly Significant Difference post hoc tests were performed as follow-up analyses. We furthermore investigated possible differences between SCD and MCI participants using *t* tests. To examine differences in game experience and perceived game efficacy ratings by sex, educational level, and socioeconomic status (SES), independent-samples *t* tests were conducted for each trained cognitive domain×rating combination. Sex (male vs female), education (median split into low vs high), and SES (median split into low vs high) were used as grouping variables. To control for multiple comparisons, Bonferroni-adjusted *P* values were calculated. Given that data were missing completely at random (MCAR, $P>.05$), we handled missing data using multiple imputation (m=20) via predictive mean matching, with group, session, and game included as auxiliary predictors. All estimates were pooled across the 20 imputed datasets following Rubin rules.

Results

Overview

In total, 132 datasets were available for analysis. Due to incomplete data resulting from technical issues (eg, data transmission errors, incomplete or faulty data storage), 16 datasets had to be excluded from further analysis (Figure 2). The technical issues did not impact training delivery and were backend-related and therefore did not interfere with players' game experience. Of the remaining 116 participants, 99 were tested in Bern and 17 in Lucerne. Groups did not differ in demographics (age, gender, and years of education) or depression ratings (all $P>.05$). SES was measured using the Swiss neighbor index of socioeconomic position (Swiss-SEP) 3.0 dataset from the Swiss National Cohort database. This postal code-based index is derived from the 2000 census and the 2012-2015 structural survey and is categorized into deciles. Table 2 depicts participants' ratings per study arm.

Figure 2. Consolidated Standards of Reporting Trials flow chart. *:Participants dropped out before the computer training started.

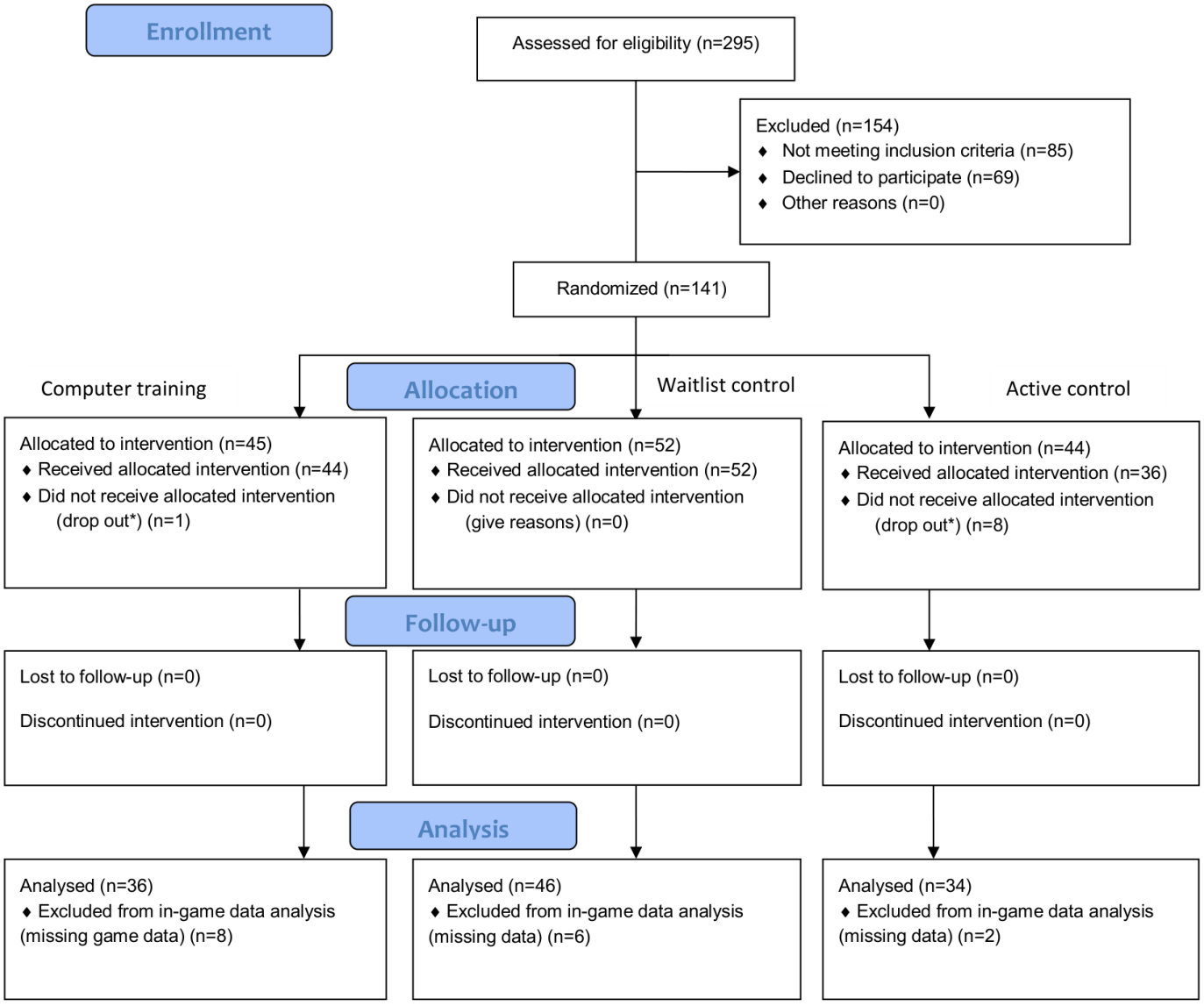


Table 2. Demographic information and questionnaire results compared by group (ANOVA) [16][a].

Total sample and groups	Total sample	Computer training	Waitlist	Active control	*P* value[b]	*F* test (*df*)	η^2_p[c]
SCD[d] or MCI[e]	89/27	31/5	32/14	26/8	—[f]	—	—
Female, n (%)	66 (56.90)	20 (55.56)	28 (60.87)	18 (52.94)	—	—	—
Living in rural areas, n (%)	36 (31)	9 (25)	15 (32.6)	12 (35.3)	—	—	—
Living in urban areas, n (%)	80 (69)	27 (75)	31 (67.4)	22 (64.7)	—	—	—
Age (years), mean (SD)	71.10 (6.51)	71.4 (6.54)	70.85 (5.79)	71 (7.35)	.86	0.13 (2,114)	0.002
Education, mean (SD)	15.33 (2.92)	15.1 (2.61)	14.74 (3.08)	16.1 (2.87)	.44	2.43 (2,114)	0.04
GDSS[g], mean (SD)	1.64 (1.70)	1.48 (1.70)	1.41 (1.34)	2.01 (2.04)	.62	1.76 (2,114)	0.03
SES[h], mean (SD)	7.23 (1.61)	7.03 (1.56)	7.27 (1.73)	7.41 (1.56)	.62	0.47 (2,114)	0.009
MoCA[i] (baseline), mean (SD)	27.17 (2.44)	26.7 (3.6)	26.93 (2.58)	27.2 (3.05)	.21	0.47 (2,114)	0.008
Attendance (weekly group sessions), mean (SD)	9.18 (1.05)	9.17 (1.00)	9.20 (0.95)	9.16 (0.99)	.86	0.026 (2,114)	0.0004
Adherence (sessions per week), mean (SD)	5.10 (0.69)	5.13 (0.68)	5.14 (0.57)	5.03 (0.85)	.97	0.30 (2,114)	0.005
Recommendation[a], mean (SD)	6.82 (1.68)	6.86 (1.90)	6.81 (1.41)	6.78 (1.96)	.74	0.01 (2,114)	0.001
Cognitive improvement[a], mean (SD)	4.86 (1.64)	5.13 (1.80)	4.90 (1.94)	4.43 (1.92)	.87	1.20 (2,114)	0.03
Ideal training duration[a], mean (SD)	28.88 (10.21)	27.2 (7.39)	31.49 (11.03)	26.1 (10.86)	.24	2.74 (2,114)	0.06

[a]Questionnaire (9-point Likert scale): Subjective ratings from post 10-week training: (1) Recommendation: How likely is it that you recommend the training to a friend? (2) Cognitive Improvement: How much do you think your cognitive performance improved after 10 weeks of training? (3) Ideal training duration: How long would you want to train each session (in minutes)?
[b]*P* values <.05 indicate significant group differences.
[c]η^2_p: Partial eta squared.
[d]SCD: subjective cognitive decline.
[e]MCI: mild cognitive impairment.
[f]Not applicable.
[g]GDSS: Geriatric Depression Scale Short.
[h]SES: Socioeconomic Status.
[i]MoCA: Montreal Cognitive Assessment.

Feasibility and Usability

Dropout was defined as discontinuation of the intervention. Once the BBT interval began, there were no dropouts in any of the three groups. We therefore did not have any participant-level missing data. As no participants dropped out once the BBT interval began, the analyzed sample is equivalent to the full randomized sample for the intervention period, rendering a separate intention-to-treat analysis unnecessary. However, during the control intervals before the BBT, 9 (6.82%) participants dropped out due to personal (n=5, 3.79%) and health-related (n=4, 3.03%) reasons [16]. Adherence to the training protocol was high across groups, with a mean of 5.10 (SD 0.69) out of 5 required and 6 possible sessions played per week and 9.18 (SD 1.05) weekly group sessions attended. Most common reasons for item-level missing data (game experience and perceived game efficacy questionnaire) were due to not attending weekly group sessions or missing individual training sessions at home on grounds of ill health, holidays, and special occasions (Table 3). In-game item-level missing data (game performance, in-game questionnaires on daily motivation, well-being, and play performance; n=16) were related to technical issues. There were no significant (*P*<.05) group differences in adherence (Table 2). Out of the 6489 sessions registered in total, 598 (9%) ended prematurely (before the 24-minute cutoff), which was mainly due to environmental distractions according to participants' feedback in the weekly group sessions. A total of 61 help button presses (0.94% of all sessions) were documented, which were mainly initiated by participants to test the functionality rather than seeking actual assistance. Among the help requests that were related to specific issues, the majority pertained to nontraining-specific functionalities, such as the use of avatars, feedback mechanisms, or the guest account.

Table 3. Game experience and perceived game efficacy ratings across all three treatment groups undergoing BBT[a] (BBT only; waitlist control and BBT; active control and BBT)[b].

Domains and subdomains	Missing, n (%)	All games, mean (SD)	Working memory, mean (SD)	Episodic memory, mean (SD)	Spatial abilities, mean (SD)	Semantic memory, mean (SD)	*P* value	*F* test (*df*)	η^2_p[c]
Game experience ratings									
Motivating	59 (4.3)	6.17 (0.95)	6.08 (1.05)	619 (0.92)	6.11 (1.05)	6.19 (0.99)	.59	0.64 (3, 301)	0.01
Difficult	32 (4.5)	4.82 (1.33)	4.71 (1.44)	5.08 (1.18)	4.99 (1.31)	4.48 (1.38)	<.001	5.52 (3, 301)	0.03
Challenging	63 (4.6)	5.53 (1.17)	5.55 (1.21)	5.69 (1.12)	5.61 (1.10)	5.21 (1.26)	<.001	7.32 (3, 301)	0.03
Entertaining	77 (5.6)	5.36 (1.41)	5.22 (1.40)	5.34 (1.42)	5.11 (1.47)	5.65 (1.43)	.007	4.20 (3, 301)	0.02
Frustrating	75 (5.4)	3.06 (1.80)	3.32 (1.83)	2.88 (1.72)	3.21 (1.85)	2.94 (1.87)	.04	2.74 (3, 301)	0.01
Perceived game efficacy									
Memory	88 (7.1)	5.69 (1.23)	5.81 (1.22)	6.01 (1.09)	5.53 (1.39)	5.23 (1.38)	.001	5.67 (3, 301)	0.06
Thinking abilities	100 (7.2)	5.38 (1.26)	5.28 (1.29)	5.43 (1.30)	5.35 (1.34)	5.30 (1.28)	.35	0.79 (3, 301)	0.01
Reaction time	101 (7.3)	4.78 (1.46)	5.21 (1.38)	4.77 (1.41)	4.57 (1.54)	4.45 (1.57)	<.001	5.91 (3, 301)	0.04
Hand-eye coordination	102 (7.4)	4.53 (1.54)	4.98 (1.51)	4.42 (1.52)	4.35 (1.51)	4.32 (1.63)	.003	4.98 (3, 301)	0.03
Multitasking	97 (7)	4.57 (1.53)	4.82 (1.52)	4.51 (1.54)	4.50 (1.63)	4.37 (1.51)	.14	1.86 (3, 301)	0.01
Everyday activities	100 (7.2)	4.70 (1.44)	4.67 (1.55)	4.81 (1.48)	4.56 (1.51)	4.56 (1.39)	.39	1.02 (3, 301)	0.01

Domains and subdomains	Missing, n (%)	All games, mean (SD)	Working memory, mean (SD)	Episodic memory, mean (SD)	Spatial abilities, mean (SD)	Semantic memory, mean (SD)	*P* value	*F* test (*df*)	η^2_p [c]
Vision	101 (7.3)	4.33 (1.64)	4.19 (1.71)	4.31 (1.65)	4.48 (1.64)	4.27 (1.72)	.62	0.60 (3, 301)	0.01

[a]BBT: Bern Brain Training.
[b]Means, SDs per cognitive domain and across all domains (all games), and one-way ANOVAs in game experience and perceived game efficacy per cognitive domain (7-point Likert scale) are reported. Missing data (n=1005, 6.31%) refers to a total of N=15,916 item-level entries over all game experience and game efficacy ratings.
[c]η^2_p: Partial eta squared.

Acceptability

In-Game Ratings of Motivation, Well-Being, and Play Performance

In an exploratory analysis, we compared in-game ratings of the groups over the course of training in play performance, motivation, and well-being (Table S3 in Multimedia Appendix 3). At baseline, groups did not differ in self-rated play performance, well-being, or motivation. For play performance, participants in the BBT group showed a significant increase over sessions (b=.010, 95% CI 0.01-0.01; *P*<.001), while the waitlist group improved significantly less over time (b=-.010, 95% CI –0.01 to –0.00; *P*<.001). The active control group did not differ significantly from the BBT group (b=–.005, 95% CI –0.01 to 0.01; *P*=.09). For well-being, no significant session effect was observed in the BBT group (b=–.001, 95% CI –0.01 to 0.00; *P*=.14) and the waitlist group had a similar trajectory (b=.001, 95% CI –0.01 to 0.01; *P*=.66), while the active control group showed a significant decline relative to BBT (b=–.005, 95% CI –0.01 to –0.01; *P*=.001). For motivation, the BBT group also remained stable over sessions (b=–.001, 95% CI –0.01 to 0.01; *P*=.36), the waitlist group showed a significant increase compared to the BBT group (b=.003, 95% CI 0.01-0.01; *P*=.02), and the active control group showed a nonsignificant trend toward decline (b=–.003, 95% CI –0.01 to 0.00; *P*=.07).

Questionnaire Ratings of Subjective Cognitive Improvement, Recommendation, Training Duration, and Side Effects

After 10 weeks of training, participants rated their subjective cognitive improvements at 4.86 (SD 1.64), and their likelihood of recommending the training to a friend was 6.82 (SD 1.68; 9-point Likert scales). The desired training duration was 28.9 minutes (SD 10.21), which exceeded the required 24-minute training duration. ANOVAs revealed no statistically significant differences between groups (Table 2). No side effects were reported.

Subanalysis of SCD and MCI

t test analyses between SCD and MCI participants showed no significant differences in measures regarding the intervention protocol and training compliance (attendance, adherence, recommendation, cognitive improvement, and ideal training duration). There was no significant difference in game-reported motivation before training (*P*=.58), well-being (*P*=.34), nor posttraining self-reported performance (*P*=.17). Analysis revealed no significant difference between SCD and MCI in terms of game experience and perceived game efficacy (for all ratings *P*>.05); therefore, the subsequent analyses do not distinguish between the 2 subpopulations.

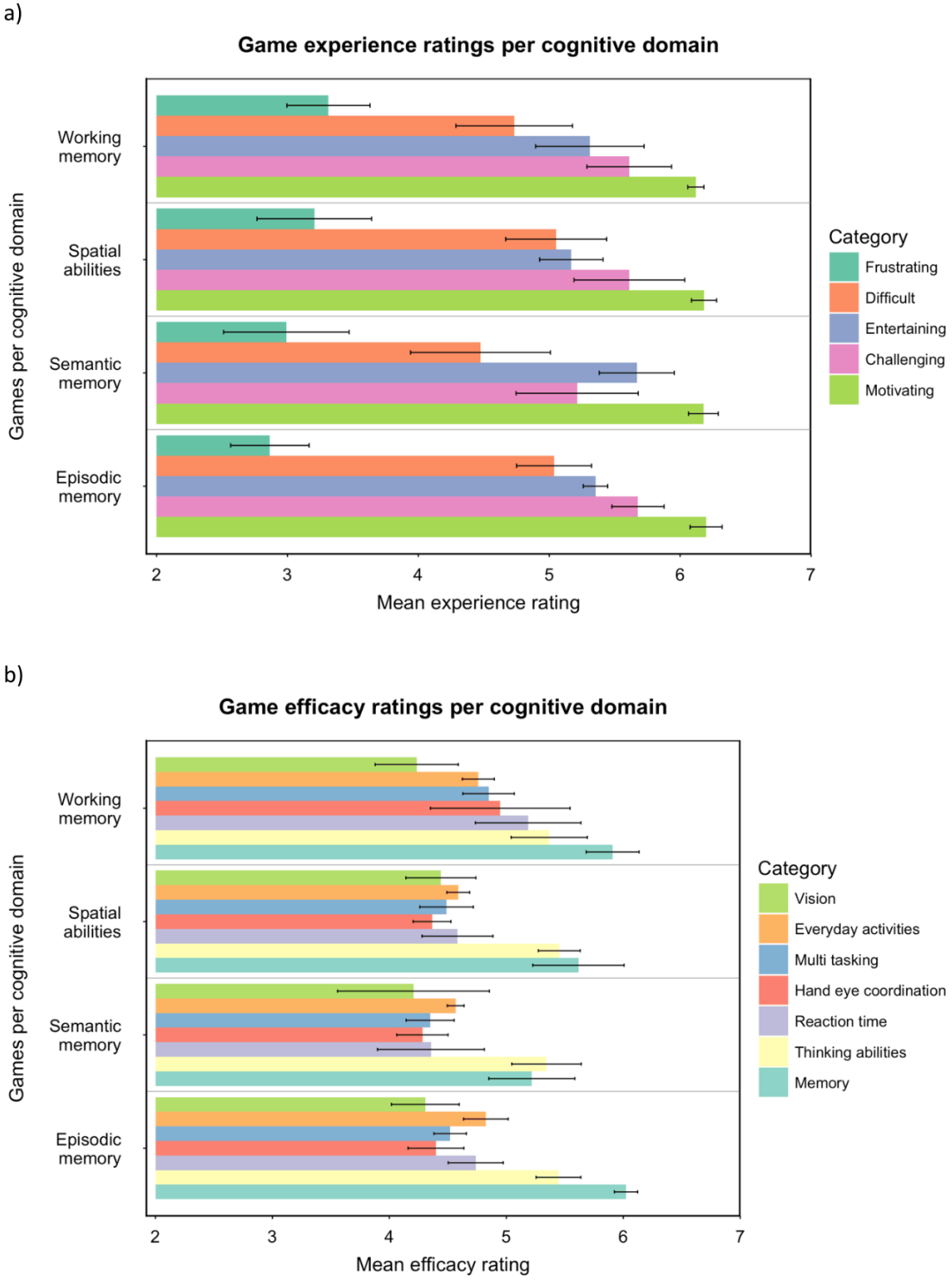
Questionnaire Ratings of Game Experience and Perceived Game Efficacy

Missing data (n=1005 out of 15,916 item-level ratings, 6.3%) were handled using multiple imputation (m 20) via predictive mean matching, with group, session, and game included as auxiliary predictors. All estimates were pooled across the 20 imputed datasets following Rubin rules. On average, participants showed very high motivation across cognitive domains and training groups (mean 6.17, SD 0.95). ANOVAs revealed significant main effects in rating game experience as difficult ($F_{3, 301}$=5.52, η^2=0.03; *P*<.001), challenging ($F_{3, 301}$=7.32, η^2=0.03), and entertaining ($F_{3, 301}$=7.67, η^2=0.06; *P*<.001). Post hoc tests showed that semantic memory games were rated as significantly less difficult than spatial abilities (*P*=.003) and episodic memory (*P*<.001) games. Importantly, on average, none of the games was rated as excessively difficult or easy (mean 4.82, SD 1.33). In line with the difficulty levels, semantic memory games were rated as significantly less challenging than episodic (*P*<.001) and working memory games (*P*=.049), while being perceived as significantly more entertaining than spatial abilities games (*P*=.047). Frustration ratings were, on average, relatively low across all cognitive domains (mean 3.06, SD 1.80). All other post hoc tests did not show significant results (Table 3 and Figure 3A).

Perceived game efficacy (Table 3 and Figure 3B) indicated that games were perceived as most efficient in training memory (mean 5.69, SD 1.23) and thinking abilities (mean 5.38, SD 1.26). ANOVAs yielded significant main effects in training memory ($F_{3, 301}$=5.67, η^2=0.06; *P*=.001), reaction time ($F_{3, 301}$=5.91, η^2=0.04; *P*<.001), and hand-eye coordination ($F_{3, 301}$=4.17, η^2=0.03; *P*=.006). Post hoc tests revealed that, for perceived memory improvement, episodic memory games were rated as significantly more effective than semantic (*P*<.001), while working memory games outperformed semantic memory games (*P*=.008). For perceived reaction time improvement, working memory games were rated significantly more effective than semantic (*P*<.001) and spatial abilities games (*P*=.045). Regarding perceived improvement in hand-eye coordination, working memory games were regarded as more effective than semantic (*P*=.02), episodic (*P*<.001) memory games, and spatial abilities games (*P*=.005). All other post hoc tests did not

show significant results. A comprehensive overview of each individual game is given in Table S2 in Multimedia Appendix 3. Groups did not differ in game efficacy ratings (Table S1 in Multimedia Appendix 3). Notably, however, the active control group experienced several training domains as less difficult, less challenging, and less effective than the other groups (Table S1 in Multimedia Appendix 3).

Figure 3. Distribution of game experience ratings (a) and perceived game efficacy (a) of the BBT across the trained cognitive domains on a 7-point Likert scale. Means and standard deviations of ratings are shown, with the lower limit set at 2 for illustration purposes. BBT: Bern Brain Training.



Subanalysis of Education, Sex, and SES

Independent samples *t* tests revealed no statistically significant differences between sex across any trained cognitive domain×rating combinations after Bonferroni correction ($P>.05$). Likewise, no significant differences were observed between participants with low versus high education levels nor between participants with low versus high SES.

Discussion

Overview

Remote CCTs provide a promising line of nonpharmacological treatment in cognitive decline [15,36]. We successfully developed the BBT, a tablet-based cognitive training app to train cognitive functions affected in SCD and MCI, through a user-centered co-design process and programmed by a professional game designer. The present findings originate from a secondary analysis of an RCT [17], in which the BBT was developed and initially evaluated. Our objectives were to (1) evaluate the feasibility, usability, and acceptability across the study population from a 10-week daily training program [16,17], and (2) to assess participants' perception of the app's effectiveness in improving cognitive performance. Feasibility was high, as reflected by strong adherence to both at-home training sessions and weekly group sessions. Participants demonstrated high motivation across cognitive domains and training groups, with no significant group differences in adherence. Usability was good, evidenced by the low number of help-button presses recorded across thousands of completed training sessions. Acceptability was also favorable, with participants reporting an entertaining game experience and low levels of frustration despite perceiving the BBT as challenging. The games were considered particularly effective for training "memory" and "thinking abilities." Finally, participants with SCD and MCI did not differ significantly in their ratings of game experience or perceived training efficacy.

Game Development and Design

Our design process was guided by expert input from relevant stakeholders (participants, patients, clinicians, and researchers) and programmed by a game designer. We put an emphasis on game diversity and individual adaptivity [12], while providing a rewarding, visually attractive, and demanding game environment [11,13]. The design and intervention environment, including ample time to familiarize with the app and the device, promotes adherence across an extended period of time [37], for which feasibility, support, and adaptivity are crucial [10,11]. Our results confirm our design efforts and show high feasibility, usability, and acceptability.

Feasibility and Usability

During the BBT interval, adherence was exceptionally high without dropouts and high attendance rates. This level of engagement is notable given that adherence to similar protocols and populations is often substantially lower: In the cognitive training element (max. n=144 sessions) of the large-scale Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability (FINGER) study [38], only 63% of participants (398/631) engaged at least once, 20% (126/631) completed at least half of the sessions, and merely 12% (76/631) completed the full training protocol. Further, in SCD populations, a web-based memory strategy program achieved an adherence rate of 50.6% (158/312) over 8 weeks [39], despite high satisfaction among completers (150/154, 97.4% of completers would recommend the training). Adherence in populations with MCI is inconsistently reported [15,40], but available meta-analytic evidence suggests that sustained engagement remains a key challenge across studies [41]. Against this backdrop, the near-complete adherence observed in the present study underscores the feasibility of the intervention and suggests that specific design features (eg, adaptive difficulty levels, weekly in-person meetings, large game selection, and appealing game design) may have been critical in supporting engagement. Moreover, older individuals and people with memory impairments may be more likely to adhere to CCT given heightened intrinsic motivation [11]. Technical support was provided via an integrated help button and in weekly in-clinic meetings. This socially stimulating group setting was further promoted by including social and multiplayer elements in the game design with the intent to enhance participant engagement and motivation [42]. Research suggests that incorporating social interaction into cognitive training programs for older adults can contribute to improved learning outcomes and promote cognitive health [43]. The importance of social interaction and continuous support is also underlined by the fact that the adherence rate was equally high in the active control group. The identical app framework was employed for the active control training, with the documentaries integrated into the same thematic landscape of virtual islands as the BBT games. Finally, the lack of observed differences between sex, education, and SES groups indicates that the BBT games provide a consistent experience across participants, suggesting their applicability across diverse user groups. This further suggests that the game design does not systematically advantage or disadvantage users based on sex, educational level, or SES. Such consistency is particularly important in the context of aging and cognitive decline, where equitable engagement across demographic groups is essential.

Acceptability

The BBT was perceived as challenging and at the same time entertaining. None of the games was experienced as excessively difficult or easy, and frustration levels were low. The games were perceived as being most effective in training memory and thinking abilities, with episodic memory and working memory games rated as most efficient candidates in driving participants' perception of efficacy.

Particularly noteworthy, when examining outcomes across varying degrees of cognitive impairment, no discernible distinctions were observed between individuals with SCD and those with MCI regarding game- and training-related measures, speaking for the versatile possibilities of implementation across this spectrum of cognitive impairment. The observed significant differences in well-being and self-perceived in-game performance can be attributed to the increased degree of cognitive impairment in the MCI group. However, we were able to uphold high levels of motivation and enjoyment across those subsamples, holding significant clinical relevance concerning the acceptability of the BBT across a range of levels of cognitive impairment.

Interestingly, we found significant differences in perceived game efficacy and experience ratings in the active control group. Having spent ample time getting acclimated to the app interface and the electronic device during the 10-week active control training, they might have perceived the subsequent BBT games as comparatively less difficult and challenging and less efficacious in refining reaction time and vision. This observation is particularly relevant considering that older adults often contend with the initial phases of familiarizing themselves with the new devices and apps, which can be inherently challenging and appears to be beneficial for cognitive functions on its own [44]. Exploratory analyses of group differences in in-game ratings across the training course further supported these patterns and suggested that being on a waitlist or undergoing an active control training before the real intervention, compared to starting with the real intervention right away, might have differential effects on user experience. Regarding self-perceived play performance, both the intervention and active control groups improved over time, whereas the waitlist group showed a significantly smaller increase. Well-being remained stable across the intervention and waitlist groups but declined significantly in the active control group, possibly reflecting fatigue effects. Finally, motivation trajectories remained stable in the intervention and active control groups, with a significant increase observed in the waitlist group. Given that self-efficacy [45], motivation [46], and well-being [47] affect quality of life and cognitive outcomes in MCI, those findings highlight the importance of monitoring these aspects during remote cognitive training interventions.

Strengths and Limitations

We singled out several strengths and limitations with the potential for future improvements of the BBT. Strengths include: (1) High adherence rate in terms of number of dropouts, sessions played, and completed sessions. We believe that this is related to the professional game design and characteristics as well as social elements, which may be crucial for the successful implementation of long-term training programs. The remarkable levels of adherence underline the importance of design and game selection [48] and lead us seamlessly to the next point; (2) Stakeholder engagement within a multidisciplinary design process was crucial in identifying and addressing barriers to successful implementation of the BBT [35]; (3) Option for a low-cost and high-frequency cognitive intervention with a beneficial side-effect profile that could be covered by health insurances [49]; (4) Accessibility for underserved older populations is supported by the growing availability and acceptance of digital technologies among older adults [9]; and (5) Remote interventions reduce traveling time and inconveniences for mobility-impaired persons and caregivers.

Limitations include: (1) focusing on patients with SCD and MCI in the analysis precludes conclusions on feasibility and usability in more impaired populations such as the different stages of AD; (2) weekly in-clinic sessions constrained accessibility. However, it was very important during the developmental phase, as it allowed us to gather important information to further refine and debug the app; (3) though we engaged key stakeholders to provide feedback throughout the game development, feedback and integration phases were not structured enough to sufficiently assess the developmental process; (4) a social desirability bias might have led participants to answer questionnaires more benevolently. This is a known challenge associated with non-anonymized self-reports but has been suggested to be a minor issue in older adults [50]; and (5) we did not control for the time of day when participants completed their at-home sessions, which may have influenced attentional levels [51]. Future research could address this by standardizing session times or including time of day as a covariate. However, variability in participant chronotypes would still limit the generalizability and validity of any conclusions drawn from such analysis.

Outlook

This innovative study contributes significantly to the field by developing and evaluating a tablet-based cognitive training adapted to the needs of older adults with cognitive impairment. The participatory design process involving end users throughout development contributed to a successful implementation. The BBT was designed for cognitive training, but future developments could extend its functionalities. Monitoring in-game performance over a prolonged period and recurrent integrated cognitive tests could help identify early signs of cognitive decline and allow tracking cognitive changes over time [52]. Previous studies suggested that cognitive training might have far transfer effects on daily functioning and quality of life [4]. Combining different games, and therefore cognitive challenges, could mimic activities of daily living by creating a more immersive game experience and possibly increase far transfer effects on daily functioning [53]. While the BBT is designed in a real-life-like manner with immersive and interactive elements, it offers a bridge between cognitive training and real-world scenarios. We believe that 10 weeks of CCT is sufficient for establishing feasibility, acceptability, and usability, including capturing engagement and identifying technical challenges and barriers to sustained use. However, future studies should explore longer training durations, the effect of booster training periods, and transfer effects to establish the practical impact of CCT on daily functioning and quality of life. The integration of additional social elements such as multiplayer elements, chat rooms, or rank lists could further enhance participant engagement and motivation for those who appreciate competitive game features and player interactions. The COVID-19 pandemic has further highlighted the need for remote interventions, during which we integrated a Zoom-based option to also deliver the weekly sessions remotely [54]. Although this was ultimately not required, future studies should evaluate feasibility, usability, and acceptability using entirely remote and hybrid delivery models. Future iterations of the BBT app could moreover benefit from enhanced customization, such as incorporating personalized game selection based on individual needs and leverage AI to boost effectiveness and engagement [55]. The app could be adapted and extended to accommodate cognitively more impaired individuals with AD. The main challenge here is to maintain caregiver-independent training, for example by

offering interactive tutorials, introducing games in smaller steps, and reducing visual distractors [36,56]. Enriching the BBT with additional games to train attention and executive functions could moreover be useful for other psychiatric and neurologic patient populations with cognitive impairments.

Conclusion

In conclusion, we successfully developed the BBT app, a multidomain cognitive training designed to attenuate cognitive decline in individuals with SCD and MCI. Our findings demonstrate that user-centered, remotely delivered cognitive training can achieve sustained training adherence in individuals with SCD and MCI, a population that is often challenging to retain in long-term interventions [57]. This supports the potential integration of the BBT app into routine clinical practice, and its remote and home-based delivery may provide a scalable, cost-effective, and widely accessible tool to promote cognitive resilience, hereby enabling earlier and more continuous support for individuals with SCD and MCI. This is particularly relevant in settings where access to specialized cognitive services is limited. Addressing current limitations and expanding functionality, future research should work in close collaboration with key stakeholders to design additional games, including games to train attention and executive functions, and explore feasibility in more impaired populations (eg, different stages of AD) and extend it to different settings, such as the care-home setting.

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Generative AI Use

The authors declare the use of generative AI (GenAI) in the research and writing process. According to the GAIDeT taxonomy (2025), the following tasks were delegated to GenAI tools under full human supervision: Literature search and systematization, Code generation, Code optimization, Proofreading and editing, Translation. The GenAI tools used were: ChatGPT-5-5, Claude Sonnet 5, Consensus. Responsibility for the final manuscript lies entirely with the authors. GenAI tools are not listed as authors and do not bear responsibility for the final outcomes.

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Data Availability

The data that support the findings of this study and the data dictionary are available from the corresponding author (AKB) on reasonable request.

Authors' Contributions

AKB, EB, MF, CK, and SK developed the app, provided clinical expertise, and contributed to the conception and design of the study. MF was responsible for game programming, maintenance, and technical support. SK is the principal investigator of the project, AKB is the co-principal investigator responsible for the second study site in Lucerne. AKB, EB, AH, and CK collected the data. EB and AH analyzed the data under AKB's supervision. All authors contributed to the drafting and revision of the manuscript.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Questionnaires.
[DOCX File (Microsoft Word File), 27 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Development and background of the Bern Brain Training games.
[DOCX File (Microsoft Word File), 8825 KB-Multimedia Appendix 2]

Multimedia Appendix 3

Additional results.
[DOCX File (Microsoft Word File), 61 KB-Multimedia Appendix 3]

Checklist 1

CONSORT-EHEALTH checklist.
[PDF File (Adobe File), 1281 KB-Checklist 1]

Checklist 2

Consolidated Standards of Reporting Trials checklist.
[PDF File (Adobe File), 125 KB-Checklist 2]

Checklist 3

Template for Intervention Description and Replication Intervention Description checklist.
[PDF File (Adobe File), 80 KB-Checklist 3]

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Abbreviations

AD: Alzheimer disease
AVLT: Auditory Verbal Learning Test
BBT: Bern Brain Training
CCT: computerized cognitive training
COGTEL: Cognitive Telephone Screening Instrument
CONSORT: Consolidated Standards of Reporting Trials
FINGER: Finnish Geriatric Intervention Study to Prevent Cognitive Impairment and Disability
MCAR: missing completely at random
MCI: mild cognitive impairment
MoCA: Montreal Cognitive Assessment

RCT: randomized controlled trial
SCD: subjective cognitive decline
SES: socioeconomic status
SPIRIT: Standard Protocol Items: Recommendations for Interventional Trials

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