Prototyping and Evaluating Bo App: A brain measurement device as a feedback tool for cognitive training

Roodabeh Seif
Roodabehseif@gmail.com
University of Siegen
Siegen, North Rhine-Westphalia, Germany

Omid Veisi
Omid.veisi.ov@gmail.com
University of Siegen
Siegen, North Rhine-Westphalia, Germany

Rainer Wieching
rainer.wieching@uni-siegen.de
University of Siegen
Siegen, North Rhine-Westphalia, Germany

Volker Wulf
University of Siegen
Siegen, North Rhine-Westphalia, Germany

ABSTRACT

Each year, the number of older adults with mild cognitive impairment (MCI) increases; their aging process negatively impacts their subjective and emotional well-being and quality of life. Artifacts from the digital world could play a significant role in preventing or reversing MCI. This study developed a smartphone application prototype, known as the Bo app, that utilizes a Functional Near-Infrared Spectroscopy (fNIRs) sensor to provide biofeedback during cognitive interventions. The goal was to coach older adults to conduct unsupervised and regular cognitive training sessions at home. It was found that designing minimalist apps kept users focused, while various feedback mechanisms, such as real-time biofeedback, daily feedback, monthly feedback, and competitive feedback, encouraged regular cognitive training sessions. The participatory design approach enabled users to benefit from smartphone applications tailored to their preferences, expectations, and needs, encouraging them to be more productive and creative.

CCS CONCEPTS

• **Human-centered computing**; • **Ubiquitous and mobile computing**; • **Ubiquitous and mobile computing design and evaluation methods** ; • **Usability test** ;

KEYWORDS

Bo App, cognitive training , brain measurement device, older adults

1 INTRODUCTION

In 2019, one billion people were over the age of 60 [22]. Growing older is not only associated with losing friends and family, but also with losing sensory, executive, and cognitive functions, as well as short-term memory and physical deterioration [5]. Dementia often begins with mild cognitive impairment (MCI). Therefore, people who suffer from MCI are more likely to develop dementia than those with normal cognitive functioning. If appropriate treatment is administered, even MCI can return to normal functioning [33]. Active interventions may delay the progression of this syndrome and improve cognitive functions [40]. Diseases can be avoided by taking steps to promote healthy aging. These include, among others, activities such as reading, playing a musical instrument, playing games, volunteering in cognitive activities [1], or meditation [6]. Performing these activities throughout the lifespan is important, even for the elderly. These activities can be carried out individually or in groups, at home or outside through associations.

Digital tools have the potential to improve the quality of life for seniors [21]. For instance, it has been proven that a portable cognitive training with Neurofeedback (CT-NF) system using 2ch NIRS positively affects the quality of life of users [28], or another study that improved users' health and cognitive performance by using an app to learn how to change physiological activity such as diaphragmatic breathing [4]. Nevertheless, researchers rarely discuss designs that enable people to measure and improve their level of brain activity in later life while in their homes unsupervised. This paper focuses on designs that could fulfill some psychological needs of older people. The following research questions were pertinent: What are the motivational factors and challenges for older adults doing cognitive training sessions at home using NeU sensor and biofeedback non-invasive methods? How should features of an application be designed to encourage older adults to do cognitive training sessions regularly and unsupervised? User experience and usability are the focus of the evaluation. The analysis consists of qualitative data such as interviews as well as quantitative usage metrics [23].

2 LITERATURE REVIEW

2.1 Technology appropriation for older adults based on Participatory Design

Gasteiger et al. conducted a four-year international project on Participatory Design in 2022, collaborating with experts, carers, relatives, and older adults with mild cognitive impairment (MCI) to address real-life challenges. This study revealed that for cognitively stimulating games to be effective, useful, acceptable, and user-friendly, it is crucial to engage end users in the design process [13]. Other research shows that a variety of design factors, such as (1) building trust, (2) improving comprehensibility, (3) ease of use, and (4) raising awareness, are relevant for the successful adoption of such platforms by older adults [3]. According to the findings, elderly people may accept technological artifacts if they perceive that these tools will improve their well-being and health. It was found that seniors preferred technological devices that offered them tailored information that could be incorporated into their daily routines. The study suggested that to gain elderly people's trust in technology, interfaces and technological artifacts should consider their physical characteristics and cognitive processes [3].

In training sessions with motor trainers and cognitive psychologists, participants were more motivated and interested in using devices when feedback was timely and tailored, and performance trends were tracked and shown [3]. Different kinds of tactile feedback [39], such as vibration feedback, improve users' satisfaction [12] as does visual feedback [17]. It is common for the elderly to experience visual and auditory difficulties, as well as reduced cognitive and motor abilities. These problems may make it difficult for the elderly to use mobile devices. However, older users can cope with these physical changes with the help of current feedback technology in mobile devices [12]. Considering the full spectrum of cognitive functions could be beneficial for providing better support for all older adults [15]. Imagery and speech should be customized according to individuals' needs and preferences to optimize interaction [13]. It was concluded from Vaziri et al.'s studies that functionalities facilitating and fostering social participation and inclusion significantly meet older adults' expectations [35]. Accordingly, these factors should be taken into account in designing any mobile health technology with integrative capabilities for older adults [3]

2.2 Measuring Brain Activity and MCI

Albert et al. (2011) suggest that, on average, 4.2% of MCIs convert to dementia every year. The annual conversion rate can range from 10 to 15% in other short-term clinical observations [2]. MCI is regarded as an early stage of dementia [24], and early intervention strategies for MCI and dementia can be achieved by modifying cerebral blood flow before the onset of frailty or MCI. Individuals with MCI are more likely to develop dementia than those with normal cognitive function. However, even MCI can return to normal cognitive function if the appropriate treatment is administered [29]. A number of prospective observational studies indicate that people who engage in mentally stimulating activities—such as reading, playing games, and learning—at an older age have a lower risk of developing dementia [11, 26].

A change in cerebral blood flow may contribute to cognitive decline [18]. The prefrontal cortex needs oxygen and glucose to function properly, and the brain increases blood flow constantly to deliver these nutrients quickly. The brain is in a state of activation when blood flow is active, and brain sensors can detect when blood flow increases in the prefrontal cortex (Solutions, 2022). Functional near-infrared spectroscopy is a portable optical sensor that allows real-time monitoring of brain hemodynamics [34]. According to these studies, non-pharmacological, multicomponent interventions can improve brain health and cognitive status in MCI participants [14]. Different methods of cognitive training sessions can be generally helpful in MCI patients and for prevention. The result is that cognitive exercises can produce moderate to large beneficial effects on memory-related outcomes [14]. Additionally, research supports the efficacy of holistic approaches (e.g., combinations of cognitive stimulation and mindfulness, Neurofeedback, exercise, and dietary modifications) that together may help improve cognition and increase grey matter volume in older adult MCI patients [10, 20].

In the absence of disease-modifying pharmacological treatments for MCI and dementia or methods to slow their progression, non-pharmacological interventions for these conditions have been developed. Numerous treatment modalities, such as mindfulness, meditation [32], and cognitive training, aim to prevent or delay cognitive decline, particularly in the early stages of the disease, while also potentially improving mood and quality of life [30] and enhancing cognitive functions, such as executive functions and attention, as well as brain structure [6]. Recent research has suggested that meditation can delay cognitive decline in the elderly [6], which could also be caused by MCI. fNIRS was used to evaluate the relative hemodynamic changes in the prefrontal cortex (PFC) during a cognitive task, and an increase in prefrontal cerebral blood flow (CBF) due to meditation was observed [7]. Reynolds et al. (2021) reported potential benefits in cognitive and mood improvements from mindfulness-based and cognitive training interventions for adults with MCI, describing it as a safe approach for elderly people. They suggested mindfulness could benefit aspects of attention, psychomotor function, and memory in MCI, while cognitive training has shown positive effects on general cognition, memory, working memory, and executive function [30]. Mindfulness therapy can also be effective in preventing dementia in MCI through a low-cost, self-directed psychosocial program. Studies have shown that mindfulness therapy can reverse cognitive decline in MCI [27].

3 METHODOLOGY

Understanding the experiences and private environment of elderly people is important for having meaningful interactions with them. Therefore, the Design Case Study method was selected as a research strategy [38], involving an in-depth investigation of an unsupervised cognitive training session for older people at home. The Design Case Study has three parts (Figure 1): empirical pre-study, design and evaluation, and appropriation. This study carried out a repetitive cycle of pre-study, design, and appropriation. Older (+60), active but retired people were selected as the target group, and the setting of the event was the living lab at the university. Active in this paper means healthy seniors who are active and can handle their daily tasks independently. While they occasionally need assistance with using smartphones and digital technology, they do not have mild cognitive impairment (MCI). The device is not intended for medical purposes, and we are not qualified to claim that the app can address or treat any issues related to MCI. Participants in this study were invited for interviews through a project that served as the research's sponsor. This research has received ethical clearance (ethic applications number = ER_31_2021, and update from 2022) from the ethical board of the University. This project recruited its participants from a digital café in the city of Siegen, called "Senecafé". The project manager introduced the participants to the authors during regular sessions held to advance the project. As a result, five people agreed to participate at different times throughout the study. Information was collected via semi-structured interviews, observations, usability tests, instant collaborative co-design, and self-report. HCI research is driven by direct feedback from interested individuals, and there were some principal questions asked of the users: What was their daily routine? How familiar were they with technology? How familiar were they with cognitive training sessions using technology? and so on. Having these conversations and interacting with users could be both a tremendous source of insight and a considerable challenge [23]. The questions could be clarified during interviews, and participant responses were explored in-depth with follow-up questions.

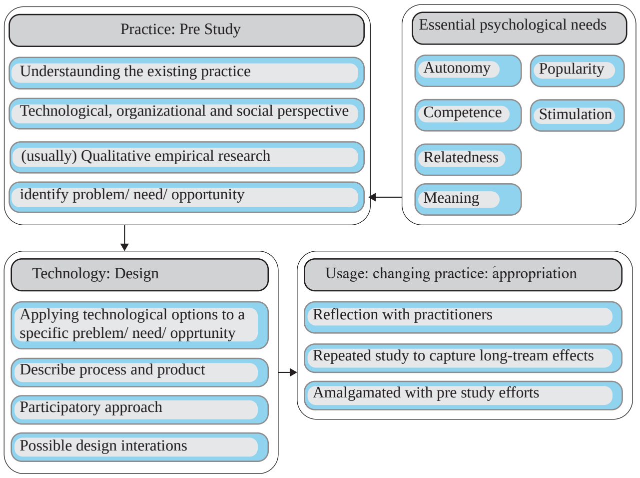

Figure 1: Research Framework.

The study consisted of iterative sessions in which older adults shared their ideas for the design. New participants were brought in to provide fresh perspectives and unbiased opinions during the different phases of the study. Some participants withdrew after a certain point because they had lost interest in co-designing this technology. Over the course of our 4 co-design sessions, stimulating games and its NeU brain measurement device, as well as the overall expectations for cognitive training, were explored. The overall goal was to evaluate the stimulating games and develop an overarching application that provides a better user experience. As such, the Bo app integrates interventions from the stimulating games and NeU device, compensates for shortcomings (e.g., lack of user onboarding and setup instructions), and adds additional features (e.g., motivating feedback and progression indicators). In the following, an overview of the content of each session is briefly presented:

In the pre-study phase, sessions with P1-P4 explored participants' initial impressions of the NeU Device, focusing on digital literacy, cognitive training preferences, and device acceptability. In the second session with P2-P4 using Bo app Prototype V1.0, their reactions during a usability test were observed, particularly regarding brain performance assessment and visual feedback (e.g., a growing plant). The third session further evaluated the NeU sensor and participants' interactions with the feedback system. Finally, in the fourth session with P4, P6, and P7, Bo app Prototype V2.0 was tested to assess usability and gather feedback on the updated version.

3.1 Participants

For the study, a total of seven senior citizens (+60) were recruited in a series of 12 co-design sessions. They were recruited from previous parts of the international academic project and mostly from a digital Café where old people were taught about ICTs voluntarily and were learning from each other. They confirm their voluntary participation in the study and that they do not have dementia or MCI. The interviews, observations, and co-design sessions were done in the living lab at the university, as well as in their private homes and online. The list of participants is shown Table 1.

3.2 Pre-study:Interviews

Participants were interviewed using a semi-structured format, with sessions lasting 1-2 hours, conducted both online and in-person to accommodate pandemic restrictions. Most interviews were in German, except one in English, and transcription was done via Meetgeek, with translations using Deepl. A German speaker facilitated discussions while the researcher observed and guided the process. Sessions began with a PowerPoint introduction of the project in multiple languages, aligning with its international scope. Interviews covered lifestyle, health, technology use, and cognitive challenges. Usability testing was embedded in the sessions, with participants' feedback contributing to prototype development. Data was coded in MAXQDA, highlighting positive and negative feedback.

3.3 Bo App Prototyping

Based on the empirical analysis of the pre-study, the first version of the prototype was designed in Figma, the web-based design platform. Several factors were considered during the design process. The visibility of system status was prioritized during prototyping. For example, several short descriptions were included in the design to keep users informed about the status of each page. To make the design more user-friendly, language that was as close as possible to the users' language was used, such as words, phrases, and concepts familiar to the user rather than internal technical terminology. Terms, concepts, icons, and images were selected based on the specific target group.

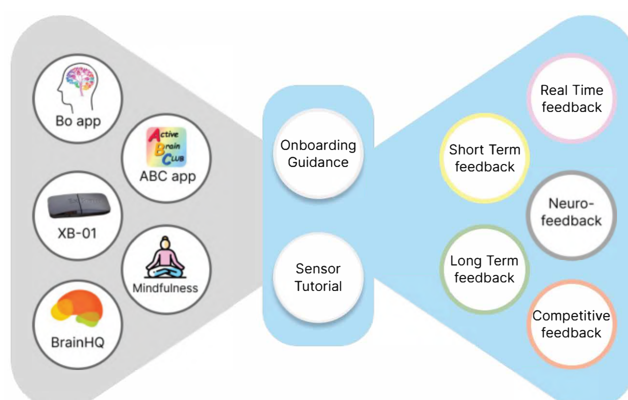

Figure 2: Bo-App infrastructure and design goals

Based on shared explorations the overarching Bo-App was co-created that integrated the ABC-App, provided instructions on how to use it, and introduced additional forms of cognitive training (e.g., meditation).

Table 1: General characteristics of the participants in the interview

ID	Age	Sex	Living situation	Job status	Digital literacy	Co-creation session
P1	65	M	Living alone	Retired	Relatively less experience	1st
P2	64	F	With husband	Retired	Good experience	1st, 2nd, 3rd
P3	71	M	With wife	Retired active in industry, finance	Relatively less experience	1st, 2nd, 3rd
P4	80	M	With wife	Electro engineer, retired	Has very good experience	1st, 2nd, 3rd, 4th
P5	71	M	With family	Retired	Has experience	3rd
P6	60	F	Partner	Retired	Relatively less experience	4th
P7	69	M	With wife	Retired	Good experience	4th

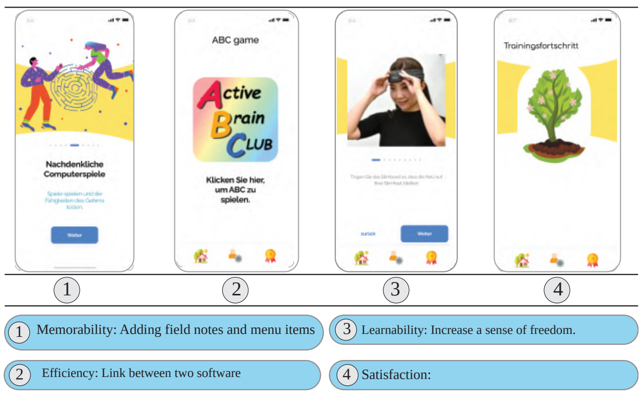

Figure 3: First version of BoApp Prototyping

3.4 Appropriation phase

Semi-structured interviews and observation methods were conducted in the mid-appropriation phase. As part of our observation, videos of the user's interaction with the system were recorded, the screen of the Android tablet (the tablet used as the main device) was recorded, and the voice of the interview was recorded. During an online interview with P4, an instant co-design session was conducted, and the design page of the Figma prototype was shared with him. He watched the design page and engaged by expressing his ideas, which were immediately applied by the researcher, and the participant determined whether or not it worked in his opinion. Concurrent usability tests were conducted with multiple interviewees using the Bo app: The number of participants impacts problem detection [16], and when there are more participants, more problems can be detected [37]. Researchers looked for ways to improve the usability of the interface based on the tasks performed in usability testing [19]. The Think-Aloud Protocol technique was used for usability testing. In addition to experiment validity, empiricism, and bias avoidance, the usability test observation session was an opportunity to see and evaluate the prototype. Therefore, the participation of a second observer was necessary. In this study, testing was based on tasks and scenarios that were representative of end-user goals. Specific, concrete tasks were assigned, but the participants were not pressured to solve a problem in any particular way, such as taking a tour of the Bo app, Login into the app, Checking your achievement and Checking your progression.

3.5 NeU sensor (XB-01)

NeU is a Brain Science company that was founded in 2017 by fusing "cognitive brain science discoveries" with "portable brain measurement technologies." Ultra-compact, weighing only 30 grams (battery included), and measuring 80 x 40 x 13 mm with a unique "butterfly-style" design that bends in the middle to conform easily to any individual's forehead (Figure 4), it can be used in conjunction with a band-type holder to stick to the user's forehead. This device uses optical topography devices (NIRS) to measure brain activity through changes in cerebral blood flow volume in real time. Cerebral blood flow (CBF) is measured using a NeU device, which uses fNIRS to measure blood flow in the user's prefrontal cortex. The non-invasive, low-cost functional Near-Infrared Spectroscopy (fNIRS) technique measures cortical blood flow [9]. fNIRS has been shown to be sensitive to both cognitive load and state, indicating that it can be used to answer a wide range of Neuroimaging research questions and provide an alternative to fMRI [9]. At NeU, they utilize an ultra-compact brain activity sensor that can be used in any environment to provide products and services based on scientific evidence. The brain's cognitive load is evaluated, and feedback is given to the user during cognition sessions. So, the state of the brain can be checked independently, and brain training can be accomplished accordingly.

4 RESULTS

This section contains the results from the various phases of our research. The study started with 7 participants; however, two dropped out before it was over. The outcomes are based on 4 co-design sessions with participants in 22 hours, which included the NeU brain measurement device and the Bo app.

4.1 Pre-study

All seven participants in this phase were familiar with using smartphones. The primary motivation for participants to join this experiment was to prevent MCI and dementia-related diseases and to maintain their independence as they aged. Some of them had experience playing video games or practicing relaxation. All of them were interested in the main goal of the system and were curious about receiving feedback on their brain performance. Moreover, participants indicated their interest was mostly related to cognitive training. However, at the beginning of this experiment, their attitude towards technology that measures brain activity was not always positive. Participant 1 stated: "The idea of AI gaining control of human life made some of them skeptical about wearing the

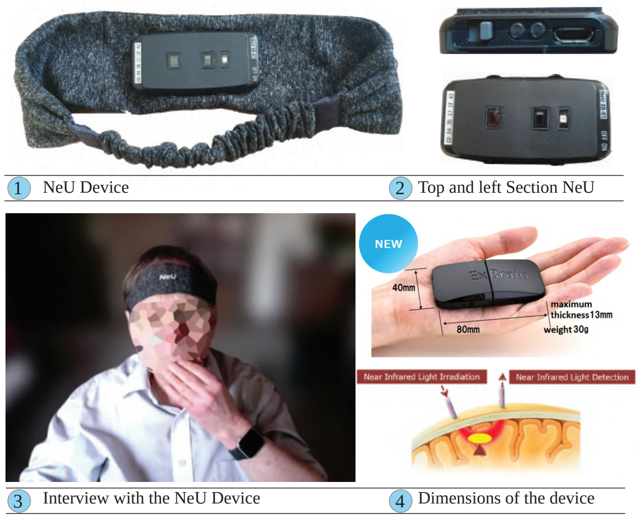

Figure 4: The NeU Device specifications

NeU device." P4 even felt nervous about experimenting, indicating he experienced the same stress during doctor appointments. By the end of the session, most participants mentioned that they had been entertained. Although one participant was nervous from the beginning, another participant was so comfortable that he forgot to take off the NeU device before leaving the room because the headband and sensor were so comfortable.

4.2 Appropriation phase

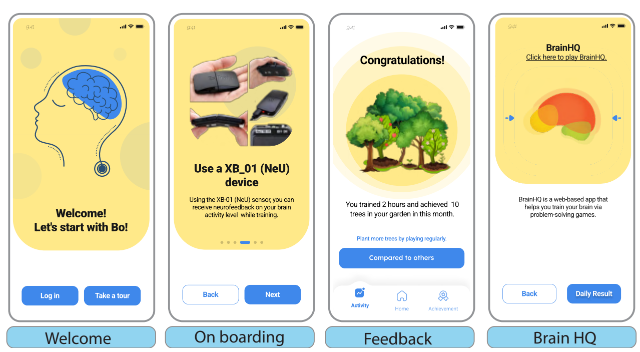

Figure 5: Final version of Bo App Prototyping

Users' ability to find content easily and complete tasks depends on the level of cognitive load on the app; therefore, minimizing cognitive load to maximize usability was considered as well. Users were prevented from having to recall information by adding field notes and menu items. They only needed to understand what they could see to perceive the interface. A sufficient amount of information was visible to them. For experienced users, shortcuts were considered so that they could customize frequent actions based on their own preferences. Users could skip the tour on the first page and go directly to the login page. Irrelevant and rarely needed information was eliminated to prevent diminishing the visibility of relevant elements. In this way, the content and visual design focused on essential information to ensure that visual elements supported the user's primary goals.

Individual cognitive ability, status awareness, preventing MCI in the future, staying independent from others, entertaining individually or with a group of people, and socializing were all different types of interests and motivations for our participants. P4 mentioned that he could not physically contact others due to his physical movement problem; however, he found the Party Game feature (one of the Bo app features) a possible solution to his need for socializing. P3 was not interested in having daily feedback on his performance because of the stress it could create, but he was interested in preventing MCI by doing training sessions. P1 was entertained by doing the Cognitive Stimulation games but was reluctant to use the NeU device due to trust issues. P2 was seeking a safe method to strengthen her cognitive abilities as well as stay independent in the future.

Traditional error messages, such as a yellow triangle with an exclamation mark, were designed with a short but complete description of the problem and what users should do to correct it. For example, when the NeU device was running out of charge, the error page displayed the solution. Furthermore, it is common for users to make mistakes in their actions, so an emergency exit was provided to allow them to leave an unwanted action without going through a long process. To foster a sense of freedom and confidence, a "Back" button was included in the main menu under all the pages. This allowed users to remain in control of the system and avoid frustration. As stated, notifications or reminders should be used sparingly, and users should have the option to customize them. Gentle reminders (e.g., "Your plants need you.") are important, but a high number of notifications can annoy users.

In this phase, users were encouraged to use the Bo apps while wearing a NeU device. Although the majority of users enjoyed the concept of using the Bo app, they had trouble putting on the NeU device, often putting it on backward or inside out as P6 and P7 mentioned "I can not use this device for more than one hour." One user proposed that the device should beep if it was not properly attached. Participants enjoyed visualizing their brain activity on the Bo app in the form of a growing tree. The monthly feedback mechanism in the shape of a nurturing garden was based on one participant's feedback. This idea also influenced the app's logo, which test users found meaningful. After adding an introductory part to the Bo app regarding the instructions for connecting and wearing the NeU device, participants were able to put on the device smoothly. Moreover, participants found the figures and visualizations of the app very helpful in conveying the 'atmosphere' of the application. One participant even started documenting his ideas, such as using different words in the app to improve it. He suggested using 'friends' instead of 'a friend' and a specific German word for cognitive health. The Bo app's features, like gamification, the use of ecological elements, user profiles, etc., appeared to make it superior to other similar apps such ABC app. The step-by-step explanation of connecting the NeU device and how to charge it also saved the user from initial confusion. In this way, the brain activity of the user could be measured while performing various activities. The activities are categorized into four different groups: meditation, free activity, and stimulation games.

Using a combination of the duration of training sessions, data gained from the sensor as shown in Table V, and the regularity of the training sessions, four different types of feedback will be provided by the Bo app for users. The data will be used to produce real-time visual biofeedback. By doing regular training three times a week without interruption, users will be rewarded with virtual water and sun to grow their trees, and they can have a fully-grown tree after one week of training; this is long-term feedback. They also receive daily feedback with numbers and a progress bar showing numeric daily feedback. The final feedback is a leaderboard, which will be produced based on the duration of the training sessions and the amount of daily progress each user achieves.

5 DISCUSSION

5.1 Significance of findings

With the aging population, there are several challenges in digital artifact appropriation for older people. Digital artifact appropriation to enhance everyday life is an important area of HCI, and older people are one of the target groups. The objective of this study was to assess the effectiveness of unsupervised cognitive training for older adults using digital artifacts enable the co-design of the interface and provide insights into older adults' responses to wearable technology. Conducting cognitive training sessions with an unsupervised approach was the novelty of this study. The designed application, called Bo app, combined with a non-invasive measuring device (XB-01 NeU sensor to evaluate the brain activity level via blood flow in the prefrontal cortex of the brain) and commercial apps can be used to promote healthy aging. Considering the research questions, a solution was needed to prevent users from giving up and to encourage and motivate them to do regular training sessions. Several features can help in this process, such as good usability, user-friendly design [36], sociability functions [25], timed and tailored feedback [3, 31], challenging games [31], and adaptable activities with users' preferences and needs [35].

Studies show that the key to motivating people to use a new app is to provide tailored, timed, and adapted feedback during the training session [3, 8, 31]. It was seen in the eventually developed versions that the Bo system was acceptable to users, which motivated them to use the NeU device and Bo app. By providing different kinds of feedback (monthly, daily, competitive, and real-time), various preferences can be supported. Vaziri et al. considered a dashboard of related and transparent health data to prevent users from being frustrated and giving up due to unrelated health data presentation, as well as to increase their awareness about their health status [35]. The Bo app was useful to participants because it provided real-time feedback (a diagram and a growing plant that inspired them with the growth and improvement of their brain functionalities in thumbnail size during the diaphragmatic breathing section). A combination of biofeedback was visualized in a diagram, score bar, and growing tree form. These satisfied various preferences and personalities of the Bo app, which can lower usage barriers by improving ease of use. Callari et al. found that the perception of a user-friendly device correlated directly with motivation to use the device. According to their results, older people were more motivated to use technological devices when they perceived them as user-friendly and believed that the technology would help them stay healthy and safe [3]. Additionally, considering heterogeneous expectations in the target group is motivating for users [35]. In the present study, supporting users with different learning paces in using the NeU sensor device via an in-app, step-by-step, visualized manual that is also skippable was another motivating factor. When other studies are compared to the current data, it can be concluded that features such as self-descriptive and informative features, socializing (Leaderboard and Game Party), adapted typography, icons, and visualizations can motivate older people.

5.2 Limitation of the research

Some potential limitations need to be considered in this study. First and foremost, because of the small number of participants and the use of a qualitative research method, the findings of this study cannot be generalized. Recruiting enough participants to provide a large sample size and well represent the population was not possible. Second, based on user feedback, the headband and sensor are not comfortable to wear for extended periods, and the temperature of the sensor rises after 20 minutes, irritating the skin on the forehead. The size of the headband is not adjustable and is sometimes too tight as well. This was the reason that one participant resigned from the upcoming interviews. Also, another participant quit because he was suspicious generally about ICTs. Third, performing physical exercises such as dance or aerobic training is significantly beneficial as a cognitive training activity and is also a user preference. However, the sensor produced unreliable data during intense movements. Also, the Bo app only exists on a conceptual level. The Figma click dummy demonstrates the potential for guiding users through cognitive training. However, it has not been evaluated with a larger number of users but rather co-created based on the preferences of seven older adults. Whether the outcome will appeal to a larger user base needs to be further explored.

6 CONCLUSION

In conclusion, it has been learned that designing minimalist apps with adequate details, considering users' physical and mental characteristics, and understanding what can deter or inspire older adults when designing for them is important. This approach encourages them to conduct unsupervised cognitive training sessions and prevents them from abandoning the sessions. Developing a well-described in-app manual that is visual and easily controllable is essential. Also, it became clear that they liked the combination of numerical scores with inspiring metaphors. They appreciate both monthly reports and real-time biofeedback on their performance; however, some do not prefer to be informed about their real-time cognitive performance because it can cause stress. Therefore, the feedback could be customized based on their preferences and different personalities. MCI prevention and cognitive empowerment are essential criteria for the health of older people. However, with increasing age, the danger of depression, loneliness, and dementia increases. A combined system as a feasible technology solution for older adults to tackle these problems is proposed, and the resulting insights are encouraging. The PD allows users to benefit from smartphone applications based on their preferences, expectations, and needs. To facilitate the interaction between users and smartphone applications, the combined Bo system was developed to guide them through the process of providing their necessary data. The evaluation of the Bo app provided many valuable insights into how older adults interact with a new sensor device that they have never encountered before, and our generally positive experiences indicate that such technology offers an exciting option.

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