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PAPER

Evaluation of a Mobile Application for Cognitive Training in Healthy Adults

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ABSTRACT

In the face of the increasing prevalence of neurodegenerative disorders and the lack of effective treatments, there is growing interest in non-pharmacological approaches for cognitive decline. Mobile applications have emerged as a promising tool for detecting cognitive disorders, providing patient training, and enhancing cognitive performance. However, the availability of applications that integrate comprehensive cognitive training, memory deficit analysis, and cognitive status monitoring across various domains for the adult population remains limited. To address this gap, the RODI application was developed and piloted with 24 adults. The usability, usefulness, viability, and efficacy of the app were evaluated, along with its preliminary effectiveness. The results indicated high ratings for usability (4.53/5.00), usefulness (4.63/5.00), viability (4.5/5.00), and efficacy (4.08/5.00). Moreover, aligned with previous research, the present study yielded findings indicating that younger participants achieved significantly higher scores and completed cognitive tasks in shorter times as compared to their older counterparts. Finally, the results of the current study findings underscore the potential of the RODI application to enhance cognitive abilities in a user-friendly and familiar setting. However, further large-scale evaluations are necessary to validate the app's effectiveness and assess its broader impact.

KEYWORDS

cognitive training, mobile application, mHealth, monitoring, application evaluation

1 INTRODUCTION

There has been a notable increase in neurodegenerative disorders in recent years, characterized by cognitive decline that frequently leads to dementia. These disorders create significant challenges for the scientific and medical communities while also raising concerns in people, their families, and society [1]. Despite extensive efforts, finding effective pharmaceutical interventions to combat cognitive decline remains elusive. Given the lack of a known cure for these conditions and

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the limited efficacy of pharmacological treatments, there is an increasing interest in investigating non-pharmacological approaches to address cognitive decline [2, 3]. Consequently, cognitive training, along with stimulation and rehabilitation, has gained attention to cope with various aspects of cognitive decline [4]. These interventions target both younger and older adults, harnessing brain plasticity to enhance cognitive reserve. The concept of cognitive reserve has been proposed to explain the lack of correlation between brain pathologies and clinical symptoms [5]. It suggests that the brain can cope with damage through compensatory mechanisms or flexible and adaptive networks, indicating its plasticity [6]. Individuals with higher cognitive reserve maintain more efficient networks, leading to better performance on cognitive tasks.

The utilization of mobile digital applications (mHealth apps) has shown potential in both detecting cognitive impairment and providing patient training to improve cognitive performance [7]. mHealth apps that focus on essential cognitive domains, including attention, memory, executive functions, and problem-solving offer a valuable means of accurately monitoring individuals' cognitive changes over time. This continuous assessment and feedback mechanism enable users to track their cognitive progress, identify areas requiring improvement, and make informed decisions concerning their cognitive health. The ability to track cognitive changes ensures that the app remains a reliable tool for personalized cognitive enhancement and ongoing cognitive well-being management. Nevertheless, notably, a few mHealth apps applications cover a diverse array of cognitive domains, function within a home-based setting, facilitate self-administration without the need for supervision, operate on a single and user-friendly mobile device, enable discreet data collection, and serve the purpose of training, evaluation, and monitoring [7, 8]. Furthermore, the lack is intensified by the expanding target population, to encompass all adults, rather than solely concentrating on individuals with cognitive deficiencies. To address this significant gap, the present study introduces an mHealth application, the Rodi app, that addresses these multifaceted needs. In the following section, the characteristics of previously developed applications that served as the basis for the design of the present application will be outlined. The next sections describe the Rodi application and outline its pilot evaluation process. The results regarding the application's usability, usefulness, viability, efficacy, and effectiveness are presented next. Lastly, the results will be discussed, and the conclusions derived from the study will be detailed.

This research aims to ultimately make a significant contribution to the current body of knowledge in the management of cognitive decline, while also paving the way for future advancements in the field.

2 MOBILE APPLICATIONS AND THEIR CHARACTERISTICS

Recent advancements in technology have created new opportunities for cognitive enhancement, and among them, mHealth applications have emerged as promising tools. In this section, the various technologies and methodologies employed in cognitive training are described, with specific emphasis on digital mobile applications and their potential to revolutionize the field [9].

It is noteworthy that many paper-based or computer-based assessments have been adapted for mobile devices, demonstrating strong correlations with traditional

and neuropsychological assessments [10, 11]. However, factors such as age, education, and technology proficiency can influence participant performance [12, 13], necessitating the establishment of new guidelines when converting traditional assessments into mobile versions [14]. Mobile assessments have been shown to enhance the reliability and efficiency of diagnostic evaluations [15]. Moreover, a direct positive association has been established between cognitive decline, mHealth assistive applications, and quality of life [16, 17]. Furthermore, the utilization of extended reality, serious games, and gamification has gained traction [18, 19]. These emerging technologies offer improved accessibility, usability, interaction, and real-time feedback to participants and clinicians. The integration of new sensors in mobile devices has facilitated the utilization of novel data streams to identify markers for monitoring cognitive decline [20]. Interventions in the form of gamified applications have demonstrated the potential to address motivational deficits and have been associated with high levels of engagement, enjoyment, and motivation compared to traditional training programs [19]. Consequently, researchers have suggested that digital cognitive training can enhance memory and motivation in patients with mild cognitive impairment (MCI) [11, 20]. Such tools provide personalized and unsupervised interventions within the participant's home environment, enabling long-term monitoring through frequent or continuous assessments of performance variability. This allows for remote, regular, and discreet data collection [1, 15, 16, 20]. Researchers have also reported that participants who utilize these applications in their home environment perform better, as they can repeat exercises and tasks [21, 22].

To develop effective mobile applications, researchers have emphasized the importance of maintaining a proper balance between task difficulty and participants' capabilities, as this balance is key to eliciting the desired level of motivation for engagement [23]. Deviations from this balance can have negative effects on participants' involvement in the intervention. Factors such as optimal task difficulty and self-efficacy play a crucial role in achieving the desired balance. Imbalances in task difficulty, such as tasks that are overly simplistic leading to boredom or excessively challenging tasks causing anxiety, can have detrimental effects on participants' engagement [23]. Additionally, tasks should be tailored to the participants, enhancing their self-efficacy by instilling confidence in their ability to perform the tasks [24]. It is worth noting that individuals with high self-efficacy are more motivated to complete tasks than those with low self-efficacy. Furthermore, mobile application design can valuably be informed by end-users themselves. The aim is to engage them as co-designers of digital applications, particularly when targeting populations with specific characteristics [25].

Notwithstanding the substantial contributions and successful advancements of digital applications as cognitive tools, there remains a compelling need to develop tools that seamlessly integrate all conceivable intervention objectives to cater to the diverse needs of the entire adult population.

3 RODI APP

The Rodi application, specifically designed for mobile devices, is intended to fulfil a twofold objective. First, it aims to deliver process-based cognitive training to enhance cognitive function and address memory deficits. Secondly, it endeavours

to function as a tool for monitoring users' cognitive state across various cognitive domains. Its primary target users include older adults who experience memory deficits, MCI, or dementia. Additionally, the application extends its usability to healthy adults with typical cognitive functioning, who are interested in evaluating and improving their cognitive reserve. By providing a comprehensive and sustainable user experience within his/her familiar environment, the application attempts to sustain the desired motivation for active engagement with the intervention, thereby increasing enjoyment associated with cognitive tasks. The RODI application aims to improve users' well-being and psychological state, while simultaneously addressing cognitive enhancement and memory decline [8]. Moreover, the application aims to facilitate the discreet collection of data and identification of trends, thereby enabling the monitoring of alterations in users' cognitive performance over time.

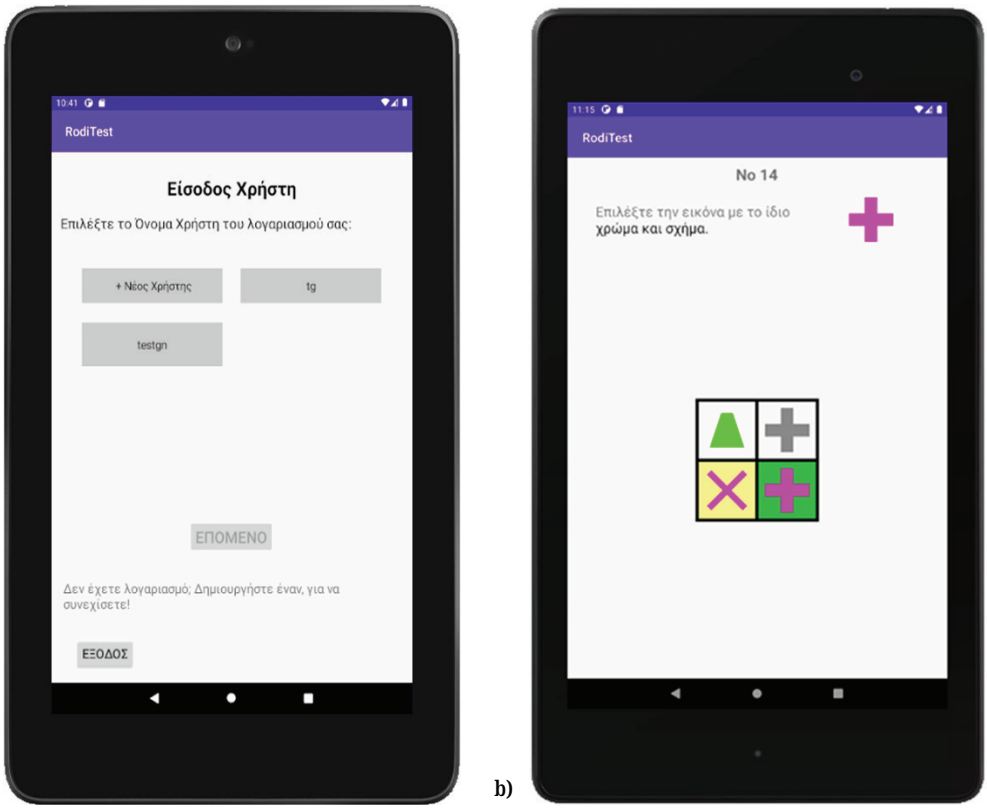

Fig. 1. a. The login screen shown here has the create new user account button and the usernames list, b. The colours and shapes task, with incorrect selection by the user

The proposed app offers graded, measurable tasks and allows users to choose the app's level of difficulty. Users can create a personal account protected by a password if desired. The app operates in two modes: "Self-Assessment" and "Practice" with four levels of difficulty. In the "Self-Assessment" mode of the application, users are subjected to a time limit within which they are expected to complete the tasks. After the assessment, a final score is generated to evaluate their performance. In the "Practice" mode, users are provided with the correct answers immediately after completing each task. Results and performance statistics are displayed in both modes, allowing users to track their progress and performance. It is worth noting that the interface language of the application is Greek.

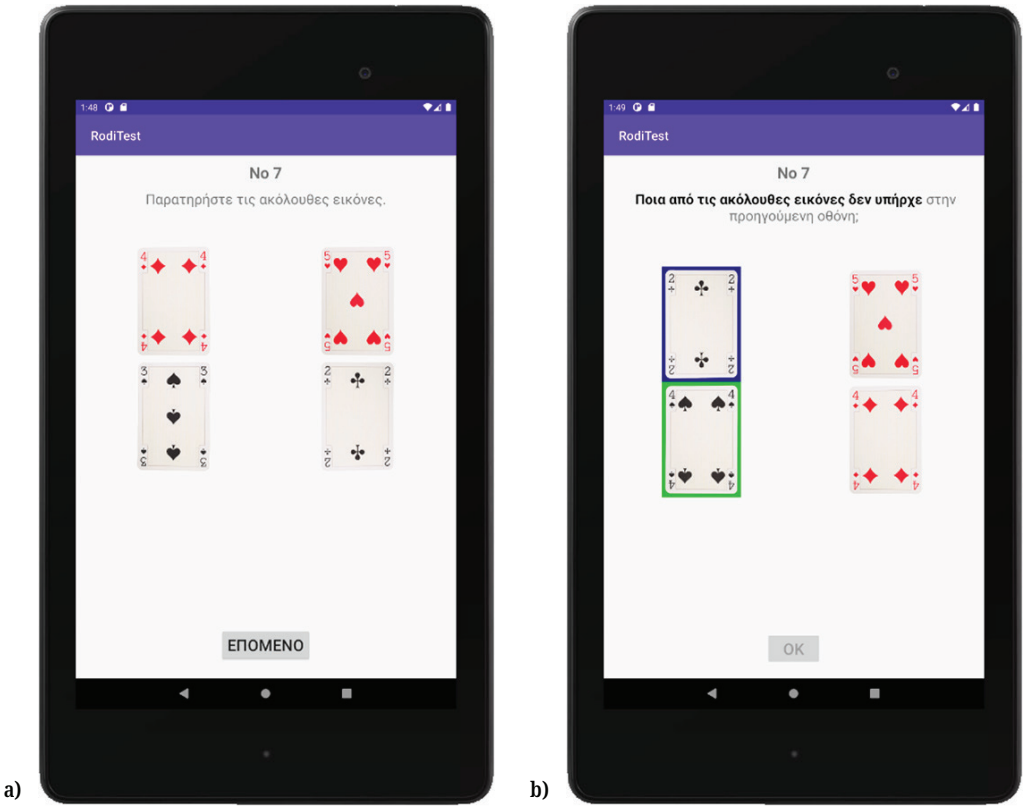

Fig. 2a and b. The new object task with a set of images as the way of presenting the possible answers and incorrect selection by the user

The cognitive tasks of the app are based on the criteria for neurocognitive disorders and target key areas related to them, to evaluate and address symptoms and deficits that affect individuals' daily activities [26]. The app's tasks encompass a wide range of cognitive domains, including complex attention, executive function, learning and memory, language, and perceptual-motor skills. These tasks cover various aspects such as divided and selective attention, processing speed, planning, working memory, feedback and error correction, habit and inhibition override, mental flexibility, immediate and recent memory, expressive language, visual perception, perceptual-motor coordination, gnosis, mental arithmetic, and problem-solving. To ensure variety, random number generators are utilized within the tasks to prevent the occurrence of duplicate scenarios.

The application encompasses a collection of 10 cognitive tasks, with four of them featuring alternative versions [27]. These variations differ either in terms of the desired answer format or in their capability for re-evaluation later. The tasks consist of a recall of an integer, which includes both immediate recall and recall after completion of tasks 2 and 4 (back task), identification of a substituted image/word (new object task), identification of objects in their original sequence (object series task), selection of a specific shape/colour (colour and shape task), performing simple arithmetic calculations (calculating task), matching missing shapes (shapes task), matching coloured shapes (colour-shape task), determining the next term in a descending sequence of integers (descending integer task), determining the number of segments in a name (name task), and matching names to pictures or vice versa (who task) [28]. Screenshots of the application are presented in Figures 1 and 2. The app evaluates accuracy and response time for each task and the difficulty levels can be adjusted

by increasing the number of elements or complexity. The application systematically records and tracks users' performance for each task, allowing for the collection and monitoring of performance data over time.

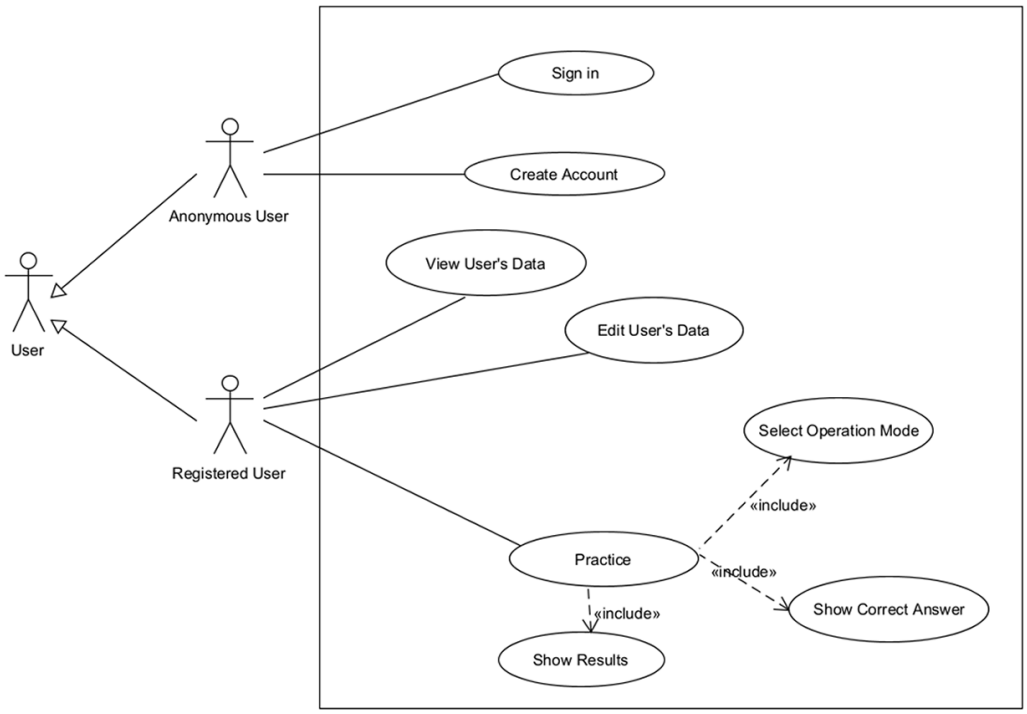

Fig. 3. The overall use cases diagram for the RODI app

The RODI app was designed for mobile devices, specifically tablets and smartphones, suitable for its target age group. The overall diagram of the application's use cases, showing the totality of actors and all the use cases, is presented in Figure 3 [27]. RODI was developed for Android 10 or earlier versions, as they meet the app's requirements. Android Studio was used in the development, as it's a free and widely used IDE for Android app development. SQLite was chosen for database management due to its integration into Android and its features.

To evaluate the usability, usefulness, viability, efficacy, and effectiveness of the RODI app in real-world conditions, it was crucial to have adult users test it. To achieve this, a suitable research protocol was proposed and approved by the Research Ethics and Deontology Committee of Ionian University, with protocol number 3600.

4 PILOT STUDY

To evaluate the usability, usefulness, viability, efficacy, and effectiveness of the RODI app as a cognitive intervention tool, it was essential to engage end users as co-designers during the app's development process. This participatory approach ensures that the app aligns with the specific needs and preferences of the target users. To achieve this goal, pilot research was carried out. The evaluation of usability entails assessing the extent to which the app can be effectively, efficiently, and satisfactorily used by specificc users to achieve specific goals within a designated context of use [29, 30]. The investigation of usefulness aimed to assess users'

intention to use or not use the application based on their beliefs about its ability to help them maintain their mental acuity and develop a positive attitude towards cognitive enhancement applications. In addition to assessing usability and usefulness, the study also examined the viability of the Rodi app, evaluating its potential for long-term sustainability and success, and users' willingness to utilize it to improve their cognitive performance in terms of both score and completion time. Furthermore, the efficacy of the app was assessed to determine its ability to consistently and reliably produce the desired effects and outcomes [30]. This evaluation encompassed assessing the app's ability to maintain a suitable balance between task difficulty and participants' abilities, mitigate deviations in engagement, and deliver the intended cognitive outcomes. Finally, the app's effectiveness was evaluated by measuring the performance of the participants in terms of the overall score and their completion time. Ultimately, the study aspired to gather feedback from the participants to enhance the interaction between the user and the cognitive tool. This feedback was intended to guide the necessary configuration of the proposed app, equipping it with essential attributes to function as a personalized and unsupervised cognitive intervention, enabling long-term monitoring and facilitating remote and discreet data collection.

4.1 Research approach

The pilot study was carried out in an elderly care centre. The participants' recruitment process involved presenting the Rodi app and the objectives of the study to the centre's managers, who were also informed of the study's approval by Ionian University's Research Ethics and Deontology Committee. The centre's managers expressed interest in the Rodi app and consented to participate in the pilot study. Potential participants' characteristics were determined, and two groups of participants were deemed necessary to be formed, as part of the user-centred process in developing and evaluating the Rodi app. One group would be composed of employees at the centre and the other of residents. A total of 24 individuals were recruited as participants in the pilot study. Finally, it was agreed that the study would be carried out during the months of June and July 2022.

4.2 Participants

The managers of the centre proposed to employees and residents to participate in the pilot study and thus 24 people aged 21 to 88 years were recruited. The sample was non-randomized and non-blinded. As already mentioned, participants were drawn from two distinct groups. Group 1 consisted of 10 care centre employees (21–60 years old), while Group 2 consisted of 14 elderly care centre residents (68–88 years old). The subjects of the Group 1, which included 10 adults (5 women and 5 men), had a mean age of 36.3 years and an average of 17 years of education (primary, secondary, and tertiary). The second group included 14 older adults (7 women and 7 men) who had a mean age of 75.79 years and an average of 12 years of education (primary, secondary, and higher education). Both groups were subjected to two exclusion criteria. Firstly, participants were required to have no visual or hearing impairments. Secondly, they were required to have no diagnosis of cognitive impairment. Table 1 summarizes the characteristics of both groups that participated in this study.

Table 1. A comparison between the demographic data of the two groups in the pilot study

Demographic Data	Group 1, Employees	Group 2, Residents
Number of participants	10	14
Age (years)	36.3	75.79
Education level (years)	17	12

4.3 Data collection method

Before the commencement of the study, participants provided informed written consent and a questionnaire was administered to collect demographic and personal information. The utilization of the Rodi app was then carried out, with all participants using the app within the same time interval (9:00 AM–12:00 PM) to ensure alertness and to minimize fatigue. Following the app usage, participants were requested to evaluate their experience by completing a second questionnaire, aimed at assessing the app's usability, usefulness, viability, and efficacy. Upon completion of the second questionnaire, participants were invited to take part in a follow-up unstructured interview.

The initial questionnaire administered to the participants focused on gathering demographic and personal information. It included questions regarding the participants' year of birth, gender, total years of education completed, place of residence, and employment status (retired or employed).

The utilization of the Rodi app in the study involved several adjustments and considerations. A modified version of the app, tailored to a single protocol form, was used to ensure consistency. This lighter version operated in default Practice mode without a time limit, and correct answers were displayed after each task. To accommodate this range of participants, the tasks were presented in random order with alternating levels of difficulty (Easy and Medium). Tasks that had variations in answer formats, such as requiring an image or a word as the answer, were presented in rotation so that participants encountered different formats each time. Certain features of the app, such as password protection, data viewing, and editing, were disabled as they were deemed unnecessary for the current study. The enabled functions in the light version included Sign In, Practice (with one mode and mixed Easy and Medium level active), Show Correct Answer, and Show Results.

In terms of data collection, the Rodi app employs Firebase Cloud Storage, a secure object storage service provided by Google. This allowed for discreet data collection, where text files containing personal or practice data were uploaded to Cloud Storage with security rules set to restrict access to only authenticated users. Digital consent was also obtained from participants before creating an account, wherein they were informed about the research's purpose, data collection, anonymization, and analysis. For the pilot study, a Galaxy Tab 4 tablet with the pre-installed light version of the Rodi app was utilized.

After using the app, participants were instructed to complete a second questionnaire to assess the application. This two-fold questionnaire consisted of 12 closed-ended questions based on the technology acceptance model (TAM) and 3 open-ended questions. TAM is widely employed in predicting the acceptance of new technologies, as studies indicate that the willingness to use technology is influenced by user acceptance [29]. The evaluation of the app focused on its usability, usefulness, viability, and efficacy. These 12 closed-ended questions were scored using a 5-point Likert scale. The open-ended questions aimed to explore participants' perspectives

regarding the app features and the benefits they experienced while using the app. After completing this second evaluation questionnaire, participants were invited to participate in a follow-up unstructured interview, which provided an opportunity for more in-depth responses to various questions.

4.4 Data collection procedure

Before participation, the study's objectives and the Rodi app were presented to potential participants, who were also informed of the study's approval by the Ionian University Research Ethics and Deontology Committee. Upon obtaining informed written consent from the participants, the researcher proceeded with the administration of the initial questionnaire, which aimed to gather demographic and personal information.

All 24 subjects participated in the administration of the application under the supervision of a researcher. Furthermore, individuals in Group 2 were accompanied by a caregiver from the care centre while using the application.

In the pilot study, participants from Group 1 initially used the light version of the Rodi app. Following the challenges identified and mentioned in the unstructured interviews, adjustments were made to improve the application and to address the difficulties in understanding certain activities and app features. As a result, participants were provided with the opportunity to use the modified version of the app for a second time. Participants in Group 2 followed, using the modified app as the second phase, benefiting from the insights derived from the experiences of Group 1. It was pre-determined that Group 2 participants would use the modified Rodi app twice.

In the analysis stage of this study, only the data collected by the study's tools during the second administration of the app to all participants were utilized. The data gathered during the first administration of the app were only used as context for the comments provided by participants during the subsequent unstructured interview. These comments were valuable in informing the modifications made to the application.

5 RESULTS

5.1 Administrations of the Rodi app

During the initial administration of the light version of the Rodi app to Group 1 participants, three out of ten employees required assistance to understand certain activities and app features. Consequently, appropriate adjustments were made to the tasks and application interface. In the subsequent administration of the modified app to Group 1, no difficulties were reported by the participants.

Group 2 participants used the modified app in both administrations. Initially, two participants out of fourteen required guidance on app usage, but this need decreased during the second use. Specifically, during the second administration, only one participant required assistance with a specific activity of the app. Additionally, three participants in this group expressed frustration and feelings of inadequacy regarding the performance evaluation presented as the percentage success rate.

As previously mentioned, the comments provided by Group 1 participants during the unstructured interview served exclusively to inform the modifications made to the Rodi app during this pilot study.

5.2 Evaluation of the Rodi app

Following the second administration of the Rodi app, participants were asked to complete a questionnaire to evaluate the application. A total of 24 questionnaires were collected, in which participants provided assessments of the app's usability, usefulness, viability, and efficacy.

Regarding the evaluation of the app's usability, the participants rated the ease of use, the functionality, and the design of the app. Concerning ease of use, the app received a rating of 4.71/5.00. Out of the participants, 70.8% (17 out of 24) gave a score of 5.00/5.00, while 29.2% (7 out of 24) gave a score of 4.00/5.00. In terms of the app's functionality, it was found that 23 out of 24 participants had a positive opinion, considering the app to be functional and without difficulties. The functionality of the app received a rating of 4.46/5.00, with 50% (12 out of 24) giving a rating of 5.00/5.00, 45.8% (11 out of 24) giving a rating of 4.00/5.00, and 4.2% (1 out of 24) giving a rating of 3.00/5.00. Concerning the design and overall appearance of the app, participants rated it as 4.42/5.00, with 41.7% (10 out of 24) giving a score of 5.00/5.00 and 58.3% (14 out of 24) giving a score of 4.00/5.00.

With regard to usefulness, the participants rated perceived usefulness, the extent to which they stayed mentally active, and their satisfaction and positivity towards using apps for cognitive stimulation and training. Out of the 24 participants, 22 found the app to be useful, with an overall rating of 4.79/5.00. Among them, 87.5% (21 out of 24) gave a score of 5.00/5.00, 4.2% (1 out of 24) gave a score of 4.00/5.00, and 8.3% (2 out of 24) gave a score of 3.00/5.00. Participants reported the app engaged them in staying mentally active, with a rating of 4.75/5.00. Specifically, 83.3% (20 out of 24) gave a score of 5.00/5.00, 8.3% (2 out of 24) gave a score of 4.00/5.00, and 8.3% (2 out of 24) gave a score of 3.00/5.00. In terms of satisfaction, participants rated the app as 4.88/5.00. Among them, 87.5% (21 out of 24) gave a score of 5.00/5.00, and 12.5% (3 out of 24) gave a score of 3.00/5.00. Participants also expressed a positive attitude towards using apps for cognitive stimulation and training, with a rating of 4.88/5.00. Out of the participants, 87.5% (21 out of 24) gave a score of 5.00/5.00, while 12.5% (3 out of 24) gave a score of 3.00/5.00.

Concerning viability, most participants, 91.7% (22 out of 24), indicated their intention to make extensive use of the app, while 8.3% (2 out of 24) held a neutral attitude. The participants' rating of their intention to extensively use the app was 4.33/5.00. Moreover, a significant majority of the participants, 19 out of 24, expressed their intention to use the app again to improve their scores. Specifically, 70.8% (17 out of 24) of participants strongly indicated their desire to reuse the app for this purpose and gave it a rating of 5.00/5.00 on the questionnaire. Furthermore, 8.3% (2 out of 24) of participants stated their willingness to reuse the app for score improvement and rated it 4.00/5.00. On the other hand, 12.5% (3 out of 24) of participants remained neutral regarding their inclination to reuse the app for score improvement, giving it a rating of 3.00/5.00, and 8.3% (2 out of 24) explicitly stated that they did not desire to reuse the app for this purpose, assigning it a rating of 2.00/5.00. However, an overwhelming majority of 23 out of 24 participants, constituting 95.8% of the sample, expressed their intention to use the app again to improve their time. Specifically, 83.3% (20 out of 24) of participants indicated an intense desire to reuse the app for this purpose, rating it 5.00/5.00. An additional 12.5% (3 out of 24) of participants expressed the desire to reuse the app for time improvement, rating it 4.00/5.00. Only 4.2% (1 out of 24) of participants stated that they did not desire to reuse the app for this purpose, rating it 2.00/5.00.

Finally, regarding the efficacy of the app, the participants rated how well the app maintains an appropriate balance between task difficulty and participants'

capabilities and their confidence in their own ability to perform the app's tasks. Particularly, concerning the difficulty of the tasks incorporated in the app, participants provided an average rating of 3.63/5.00. Specifically, most participants, 70.8% (17 out of 24), rated the tasks with a difficulty score of 4.00/5.00. A portion of participants, 20.8% (5 out of 24), gave a neutral rating of 3.00/5.00 for task difficulty, while a smaller subset, 8.3% (2 out of 24), rated the tasks as relatively easy with a difficulty score of 2.00/5.00. Furthermore, when asked about their confidence in their ability to perform the app's tasks, most participants, 83.3% (20 out of 24), expressed feeling confident. Among them, 29.2% (7 out of 24) felt strongly confident, assigning a rating of 5.00/5.00 to their confidence level. Additionally, 54.2% (13 out of 24) felt generally confident, providing a rating of 4.00/5.00 for their confidence, with a smaller proportion of participants, 12.5% (3 out of 24), giving a neutral rating of 3.00/5.00. Only 4.2% (1 out of 24) of participants reported a lack of confidence in their ability to perform the app's tasks, assigning a rating of 2.00/5.00 to their confidence level.

Table 2 presents the results for each parameter derived from the assessment of the Rodi app questionnaire, obtained through the 12 close-ended questions. The table provides an overview of the participants' ratings and preferences.

Table 2. Assessment results for each parameter of the Rodi app

Parameter	Rating Scale					Mean (SD)
	5	4	3	2	1	
Ease of Use	70.8% (17/24)	29.2% (7/24)	–	–	–	4.71 (0.46)
Functionality	50% (12/24)	45.8% (11/24)	4.2% (1/24)	0% (0/24)	–	4.46 (0.59)
Design	41.7% (10/24)	58.3% (14/24)	–	–	–	4.42 (0.50)
Usefulness	87.5% (21/24)	4.2% (1/24)	8.3% (2/24)	–	–	4.79 (0.59)
Assisting Mental Activity	83.3% (20/24)	8.3% (2/24)	8.3% (2/24)	–	–	4.75 (0.61)
Satisfaction	87.5% (21/24)	–	12.5% (3/24)	–	–	4.08 (0.50)
Positive Attitude	87.5% (21/24)	–	12.5% (3/24)	–	–	4.88 (0.34)
Intention to Use	91.7% (22/24)	–	8.3% (2/24)	–	–	4.33 (0.64)
Intention to Improve Score	70.8% (17/24)	8.3% (2/24)	12.5% (3/24)	8.3% (2/24)	–	4.42 (1.02)
Intention to Improve Time	83.3% (20/24)	12.5% (3/24)	–	4.2% (1/24)	–	4.75 (0.65)
Task Difficulty	–	70.8% (17/24)	20.8% (5/24)	8.3% (2/24)	–	3.63 (0.65)
Confidence in Abilities	29.2% (7/24)	54.2% (13/24)	12.5% (3/24)	4.2% (1/24)	–	4.08 (0.78)

Participants were also invited to share their perspectives on the app's features and the benefits they experienced while using it with open-ended questions. Their responses reveal several recurring themes. Participants highlighted that the app's activities provided them with active cognitive stimulation, contributing to their engagement and mental exercise. The visual elements incorporated into the app were deemed beneficial, enhancing the overall user experience; participants appreciated the changing imagery within the app, which added variety and novelty to their cognitive training sessions. The convenience and personalization features, such as the option to select their username from a list during the sign-in process,

were positively evaluated by participants, as they felt a sense of ownership and customization. Lastly, participants highly valued the feedback provided by the app, emphasizing its importance in monitoring their progress and offering insights into their performance. As one male Group 2 participant expressed "The feedback feature was particularly valuable as it addressed the common lack of feedback in daily activities."

During unstructured interviews, participants were asked about their willingness to use the app in the future. All participants expressed their interest in using the Rodi app or a similar app. Additionally, some resident participants mentioned their desire for the app to complement their healthcare and expressed a preference for receiving support from an expert. However, it is worth noting that two resident participants expressed concerns regarding the possibility of excessive reliance on the app. As a female resident stated: "I have concerns about excessive usage of the app, potentially leading to it replacing human healthcare providers like doctors and nurses."

5.3 Performance analysis Rodi app

A total of 48 data sets were collected from Firebase storage after the two administrations of the Rodi app to the 24 participants. The data from the first administration of the app per participant were excluded from the analysis. Instead, the data from the second administration of the Rodi app for each participant were subjected to further analysis. This approach allowed an initial examination of the participant's performance on the app, providing preliminary insights into its effectiveness. Participants in Group 1 received a mean score of 11.98 out of 15; the range for their scores was 9.7 to 13.8. With a minimum completion time of 175 seconds and a maximum completion time of 616 seconds, Group 1 had a mean completion time of 414.5 seconds (Table 3). Participants in Group 2 received a mean score of 8.61 out of 15, with a minimum score of 5.2 and a maximum score of 12.8. With a lowest completion time of 427 seconds and a maximum completion time of 1164 seconds, Group 2 had a mean completion time of 687.07 seconds (Table 3).

Table 3. Score and completion time for each group

	Group 1		Group 2	
	Score	Time	Score	Time
Mean	11.980	414.50	8.614	687.07
Median	12.000	413.00	7.850	617.00
Std. Deviation	1.127	129.974	2.190	223.776
Minimum	9.7	175	5.2	427
Maximum	13.8	616	12.8	1164

A t-test analysis was carried out to determine if there were statistically significant differences between the means of the two groups. The results of the t-test analysis showed that the mean score of Group 1 participants in the Rodi ($M = 11.98$, $SD = 1.127$) was significantly higher ($t = 4.91$, $DF = 20.38$, $p < .001$, two-tailed test) than that of Group 2 participants ($M = 8.61$, $SD = 2.19$). Additionally, the mean time taken by Group 2 participants to complete the Rodi app ($M = 687.07$, $SD = 223.77$) was significantly higher ($t = –3.44$, $DF = 22$, $p = .002$, two-tailed test) compared to the mean time taken by Group 1 participants ($M = 414.5$, $SD = 129.97$).

6 DISCUSSION

The Rodi app was specifically designed and developed as an mHealth app dedicated to process-based cognitive training, as well as the assessment and monitoring of cognitive performance across diverse cognitive domains. Its primary focus is on older adults who may experience cognitive deficiencies, as well as other healthy adults with normal cognitive function. With the aim of offering a comprehensive and sustainable experience, the Rodi app enables users to engage in cognitive training whenever and wherever they desire. The app facilitates discrete data collection and identification of trends, thus serving as an effective tool for monitoring changes in cognitive performance over time. To ensure the Rodi app's usability, usefulness, viability, efficacy, and effectiveness as a cognitive intervention tool that enhances engagement and enjoyment, a crucial step in its development process involved actively incorporating end-users as co-designers.

In the initial version of the application, the interface design aimed to prioritize user-friendly navigation [31]. Several design elements were employed to achieve this goal. A large font was used for text to enhance readability. Photos inspired by commonplace things were used to provide a realistic and familiar visual context. Large buttons were integrated into the user interface to enhance usability for users with limited manual dexterity in the context of touch-based devices. The incorporation of larger buttons effectively increased the target area, thereby mitigating the possibility of unintended touches [32]. The colour palette chosen for the interface incorporated more conservative colours and high contrast between the foreground and background elements. This design choice aimed to enhance legibility and visual clarity by ensuring a clear distinction between text and background. High contrast also helped make content more readable and accessible for people with visual impairments. The screen design was deliberately structured to prioritize user convenience by reducing the number of available options, thereby facilitating the tracking of user interactions within the app. During the design and implementation phase, significant attention was dedicated to reducing the presence of extraneous information on general screens. Additionally, the utilization of scroll bars was minimized whenever feasible, as their presence tends to introduce complexities in the navigation process for users. These design considerations were implemented to enhance user accuracy, satisfaction, and overall interaction experience. The goal was to create an environment that promotes efficient and error-free interactions, leading to improved user outcomes and a positive app experience.

Both the initial and subsequent administrations of the app yielded valuable insights that were utilized in refining the final version of the Rodi app. While the application was initially designed to be user-friendly and visually appealing, improvements were made based on observations from both administration phases. These modifications aimed to create a more seamless and enjoyable user experience for the participants. The findings from the unstructured interviews conducted after the initial administration of the Rodi app revealed certain issues with specific app features. In the first group, three participants required assistance in using the app during the initial administration. Consequently, adjustments were made to improve the clarity of task instructions and enhance user interface elements. The second administration of the modified app demonstrated no difficulties. The second group of participants was provided with the modified app, and they reported a satisfactory experience with its usage. Importantly, no issues because of age-related visual decline or manual dexterity were reported among this group.

As mentioned earlier, the participants included in the study did not have significant vision impairments, and both groups demonstrated the required skills to

effectively use the app. Surprisingly, the second group, consisting of older participants who potentially had reduced digital skills, were able to use the app on the mobile device without any difficulties. Their ability to utilize the app and their satisfaction with the experience contradicted initial expectations and supported previous research findings [16, 32]. These results suggest that age alone may not be a determining factor for the ability to use mobile apps, and older adults can successfully engage with technology when provided with user-friendly interfaces.

The participants in the study positively responded to the inclusion of real-time result presentation, which provided feedback after each answer. They appreciated the display of the correct answer without explicitly highlighting their incorrect response, enabling them to compare their answers effectively. However, some participants in the second group expressed frustration and a sense of defeat with the overall performance evaluation presented as a percentage success rate on the final screen of the app. To address this concern, the display of the app's total results was modified to only show the number of tasks completed correctly out of the total number of tasks. This change was implemented to provide a clearer and more meaningful representation of participants' score, addressing their frustration and enhancing the validity of the performance evaluation.

The feature that displays a list of users who have previously logged in and the ability to choose their usernames from this list, received positive feedback from participants. This feature was praised for its simplicity and adaptability for both individual users using their own devices and groups of users sharing a device. The ability to choose their username from the available list was especially valued by the participants since it improved personalization and created a more customized user experience.

The app's usability and usefulness received high ratings from participants. They claimed that the software lived up to their expectations and had a pleasant user interface. Participants indicated that the software met their expectations by comparing its design to that of other mobile apps available for purchase. Participants highlighted the advantages of visualization and changing visuals in the app in their open-ended comments. They perceived these aspects to be interesting and fun, which improved their experience with the activities as a whole. The utilization of images and visual elements within the app provided a dynamic and interactive experience, effectively engaging and inspiring users [31, 32].

Participants also made clear their intent to utilize the app extensively and integrate it into their daily routines, thus supporting the viability of the application. They stated that they wanted to keep using the app to achieve better results or faster completion times. The app's real-time feedback on their performance was identified as a key motivation. The participants valued the quick feedback they received since it let them track their development, pinpoint their advantages and shortcomings, and make the required corrections to improve their performance. The feedback offered a sense of accountability, which enhanced motivation and commitment to using the app [23]. The participants' positive comments about the app's features and their stated intentions to continue using it, demonstrate the app's effectiveness in inspiring the users to engage with the intervention.

Based on the evaluation questionnaire and participants' feedback, it can be concluded that the app successfully achieved its objective of enhancing participants' self-efficacy and maintaining a suitable balance between task difficulty and participants' abilities. The positive ratings and absence of strictly negative feedback indicate that the app was well-suited for both target populations and that the tasks included in the app effectively challenged participants' cognitive abilities. Participants stated

that the app provided them with an opportunity to exercise and challenge their cognitive abilities. These findings support the effectiveness of the app in promoting cognitive stimulation, self-efficacy, and motivation while preventing disengagement among the participants. The attractive and user-friendly interface, combined with engaging tasks, may encourage participants to continue using the app, contributing to improving cognitive performance.

Finally, the decision to assign the pilot study participants into two distinct groups facilitated the evaluation of the application's effectiveness as a cognitive tool. Through a comparison of the performance between Group 1, consisting of employees, and Group 2, comprising elderly care centre residents, notable differences emerged. Specifically, the younger adults in Group 1 exhibited higher scores and faster completion times in cognitive tasks compared to Group 2. These findings are consistent with previous research highlighting age-related declines in cognitive abilities [4, 33, 34].

The potential of the Rodi app extends to other mature adults with normal cognitive function who have not exhibited any signs of cognitive impairment. This demography presents an opportunity for early detection of cognitive disorders or the evaluation of cognitive reserve. Additionally, the app can target individuals who face challenges in accessing adequate healthcare services or reside in regions with lengthy waiting lists, potentially discouraging them from seeking medical care.

7 CONCLUSION

The increasing prevalence of mHealth applications and the integration of digital technologies in diagnosing and supporting individuals with cognitive disorders have received significant attention in both research and commercial domains. Considering these opportunities, the Rodi app was specifically designed and developed as a mobile tool for process-based cognitive training, as well as the evaluation and monitoring of cognitive performance across various cognitive domains. The app primarily targets older adults with cognitive deficiencies, including those with MCI or dementia, as well as cognitively healthy adults with normal cognitive function. Rodi app aims to provide a comprehensive and sustainable experience within the users' familiar environment, wherever and whenever they desire.

In this pilot study, user-centred design and evaluation by end-users were employed to explore the potential of the Rodi app to meet its goals. Based on the feedback, the application possesses the essential features to fulfil its purpose according to the end users. The positive evaluation of the Rodi app's usability, usefulness, viability, and efficacy as a cognitive intervention tool that enhances engagement and enjoyment indicates that the app aligns with the needs and preferences of the target users. Positive aspects highlighted by participants included the visual elements, changes in images, feedback, and active stimulation provided by the app. Participants expressed a strong desire to continue using the app or similar cognitive applications in the future, emphasizing the importance of such tools in enhancing cognitive abilities among adults.

The main limitations of this study include the non-randomized and non-blinded sample selection, the small sample size, and the short intervention duration. Both groups of participants were required to meet specific exclusion criteria, including the absence of significant visual or hearing impairments, or diagnosed cognitive impairment. While the initial findings from the pilot study are promising, additional investigations are necessary to establish the app's efficacy. Therefore, further

research is needed to thoroughly assess the RODI app as a cognitive training, evaluation, and monitoring tool. The app's design features, which align with criteria for neurocognitive disorders, target relevant cognitive domains, and offer diverse tasks, rendering it promising for addressing cognitive deficits. However, rigorous scientific studies are crucial to establish the app's validity and effectiveness in improving cognitive function across a larger and more diverse sample that includes individuals with varying degrees of cognitive impairment. The expanded study population will provide valuable insights for optimizing the app's effectiveness and tailoring it to the specific needs of different user groups. Longitudinal studies are also necessary to assess the app's ability to facilitate cognitive training and monitor cognitive changes over an extended period.

In addition to the perspectives mentioned earlier, several other areas of investigation warrant exploration regarding the RODI app. One such area is the examination of the app's full version, including its active features that were not utilized in the current study. Analysing the complete dataset collected by the app, such as user demographics, task completion times, time spent on each screen, and any corrections made before submitting final answers, would provide valuable insights. Furthermore, investigating the app's interaction with other technological tools that provide digital and biological biomarkers could yield useful information. Exploring how the app integrates with such tools can enhance our understanding of its role in clinical settings. The ability of the app to serve as both a cognitive training intervention and as a tool for obtaining measurements, underscores its value in future research.

In conclusion, cognitive interventions in the form of mobile-appropriate applications offer an engaging approach to screening and providing primary healthcare services, potentially alleviating the burden on the healthcare system [35, 36]. The combination of user-friendly apps with self-administered tasks allows for large-scale screening and automated assessment, without incurring additional costs. However, the integration of these applications into healthcare systems and the formulation of healthcare information policies require further examination [37]. Understanding the attitudes and needs of app users is crucial for developing more engaging apps that motivate adults to self-monitor and improve their cognitive function. While remote assessment and cognitive training can be conducted unsupervised using mobile devices, the presence of clinicians during sessions and evaluations allows for professional judgment and the collection of data necessary for accurate diagnosis. It is important to note that these interventions cannot replace regular visits with specialists. However, they can complement the work of healthcare professionals by providing additional data and measures on the course and cognitive status of patients. Future research should focus on refining these mobile interventions, ensuring their seamless integration into healthcare systems, and evaluating their long-term impact on cognitive health and patient outcomes.

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