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PAPER

Enhancing Cognitive Performance and Monitoring through a Mobile App: Insights from the Rodi Study

Panagiota Giannopoulou[1](✉), **Panayiotis Vlamos**[1], **Mary-Angela Papalaskari**[2]

[1]Ionian University, Corfu, Greece

[2]Villanova University, Villanova, USA

c16gian@ionio.gr

ABSTRACT

The prevalence of neurocognitive disorders has led to increased interest in mobile health applications (mHealth apps) for detection and training. However, there's a need for apps that integrate comprehensive cognitive training, assessment, and monitoring in personalized contexts. The RODI app was meticulously developed with the objective of catering to individuals with deficits as well as healthy adults. In this study, 11 participants without diagnosed impairments used the app twice weekly for eight weeks. Results show a consistent enhancement in cognitive performance within the app over time. Notably, a discernible divergence is observed, with the rate of improvement appearing to be comparatively slower in the younger age group in contrast to their older counterparts. Furthermore, the study assesses the reliability of the application using the intraclass correlation coefficient (ICC), confirming its consistent performance across repeated administrations. Finally, the app's capacity to monitor participants' cognitive status across various domains is investigated, unveiling controlled variations that indicate foreseeable outcomes within defined parameters. These findings underscore RODI's potential for cognitive enhancement and monitoring, offering insights into user needs and the broader significance of mobile app interventions for cognitive well-being and future research in this field.

KEYWORDS

cognitive decline, mHealth app, cognitive training, cognitive monitoring

1 INTRODUCTION

Over the recent years, the prevalence of neurodegenerative disorders characterized by cognitive decline has risen significantly, presenting challenges for both the scientific and medical communities and raising concerns among individuals, families, and society [1]. In response, there is a growing interest in exploring non-pharmacological approaches to address these challenges [2], [3]. Cognitive training, stimulation, and rehabilitation have gained attention for addressing various aspects of cognitive decline [4], [5], targeting both younger and older adults. These interventions

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aim to leverage brain plasticity and enhance cognitive reserve by capitalizing on the brain's adaptability to environmental demands [6]–[9], while simultaneously countering damage through adaptive networks, underscoring its intrinsic plasticity [10].

The integration of novel sensors into mobile and wearable digital technology has ushered in a new era of Assistive Applications, catering to a wide spectrum of needs and challenges across various life domains. Within the realm of supporting individuals with cognitive deficits, the utilization of mobile health applications (mHealth apps) has emerged as a promising strategy. Leveraging the capabilities of the Internet of Things (IoT) and facilitating Big Data analysis, these applications tap into the potential of technology. Through the integration of these innovative technologies, focused mHealth apps have been developed to deliver targeted and effective cognitive interventions.

In the pursuit of cognitive improvement, mobile applications have risen as crucial assets, with mHealth apps particularly distinguished by their convenience and ease of access [11]. Furthermore, these apps have showcased their potential not only in detecting cognitive decline but also in enhancing cognitive performance [12]. Although many traditional assessments and training interventions have transitioned to mobile devices, factors such as age, education, and technological familiarity can impact performance [13], [14], necessitating the establishment of novel guidelines [15]. The incorporation of extended reality, serious games, and gamification has amplified accessibility, user-friendliness, interaction, and feedback [16], [17], while the integration of innovative sensors enables the derivation of new data streams for monitoring cognitive decline. Gamified applications effectively address motivational deficits and offer engaging experiences that encompass enjoyment and motivation [17]. Digital cognitive training, especially within a home environment, yields improvements in memory, motivation, and the ability for long-term monitoring [1], [18], [19]. Involving users as co-designers plays a pivotal role in enhancing application design and tailoring it to the needs of specific user groups [20]–[22].

Despite the promising potential, only a limited number of mHealth apps encompass a wide range of cognitive domains, operate in home environments, and fulfill the roles of training, assessment, and monitoring for both individuals with cognitive impairments and cognitively healthy adults. In response to these existing gaps, the RODI app was developed to fill these multifaceted requirements [23], [24].

2 THE RODI APP AS A TOOL FOR COGNITIVE TRAINING AND MONITORING

The RODI app (Figure 1) is a mobile-specific intervention that has been meticulously designed to ensure user-friendliness on mobile devices, facilitating active engagement in cognitive tasks while fostering motivation and enjoyment [25]. The RODI app is designed to serve a twofold purpose. Primarily, its core objective is to offer process-based cognitive training, aiming not only to enhance cognitive functioning but also to tackle deficiencies across diverse cognitive domains. Additionally, the RODI app aims to offer several advantages in the domain of cognitive monitoring. It has been developed to enable continuous and iterative assessment, discreet data collection, and trend analysis, thereby facilitating the tracking of changes in users' cognitive performance over extended durations. This multifaceted approach aspires to provide a more comprehensive understanding of cognitive abilities and their fluctuations, which conventional assessment methods might struggle to reveal. At this juncture, it is crucial to emphasize that the tasks incorporated into the app are randomly generated in each session to maintain consistent levels of difficulty and to

prevent constraining the potential for learning outcomes. By harnessing the potential of the RODI app, the ultimate goal is to empower users to enhance the examination and analysis of their cognitive performance, thereby facilitating support from clinicians and experts to make well-informed decisions and implement personalized interventions. While the primary target audience comprises older adults dealing with cognitive deficits, the application's utility extends to healthy adults who are interested in evaluating and improving their cognitive reserve. The app's architecture is conducive to independent engagement in cognitive tasks within environments and timeframes that align with individual preferences. Functioning on a solitary mobile device, the RODI app offers a user-friendly and readily accessible solution for individuals endeavoring to elevate their cognitive function and vigilantly monitor their cognitive performance. By amalgamating these features, the RODI app's overarching objective is to empower users to take an active role in managing their cognitive well-being.

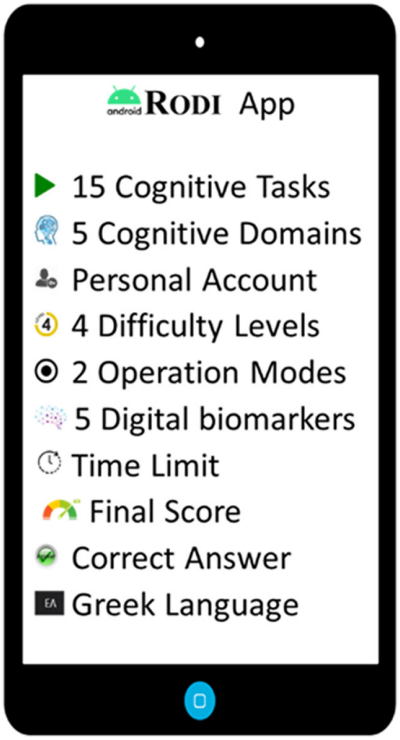


Fig. 1. The RODI app

To probe the app's effectiveness in achieving these articulated objectives, a research study was initiated. The study aimed to a) explore the app's potential as a cognitive training tool designed to enhance crucial cognitive functions, and b) meticulously examine the app's capability as a cognitive monitoring tool, specifically investigating the possibility of the data collected by the application serving as a tool for detecting real-time trends and identifying alterations in users' cognitive performance. The research was conducted among adults exhibiting age-appropriate cognitive function and has been approved by the Research Ethics and Deontology Committee of Ionian University.

3 MATERIALS AND METHODS

Initially, potential participants were invited to join the study through email invitations sent by the management of the elderly care center. Recipients of these

invitations included center employees, their relatives, as well as relatives of center residents. Those who expressed interest in participating were provided with detailed information by the researcher regarding the intervention's objectives, implementation process, and duration. It was clarified that participants would need to utilize their own Android tablet or smartphone for the intervention as mobile devices were not provided. Following this communication, the researcher did not have further interactions or meetings with the participants. Individuals who agreed to participate provided signed written consent. Individuals with visual, hearing impairments, or diagnosed cognitive impairments were excluded from participation. Additionally, individuals who had previously participated in the pilot study and those who did not possess a compatible mobile device for the RODI app were also excluded from this intervention.

Subsequently, the requisite files for installing the lighter version of the RODI application were provided to participants of this intervention through Google Drive. These files encompassed a .apk file and a .json file essential for installation, in addition to a text file that included guidelines for account creation, digital consent, input of demographic and personal information, and utilization of the practice mode within the application. The designated folder containing these crucial files was shared among 16 individuals. In cases where elderly participants required assistance, younger family members facilitated the entire process. However, two out of the 16 individuals who received the application did not employ it. Furthermore, an additional three individuals either merely created an account or did not fulfil the stipulated number of sessions. Before setting up their person-al accounts on the RODI app, each participant was subjected to supplementary digital consent procedures.

3.1 Participants

All participants in this intervention were volunteers who exhibited normal cognitive status for their age, and none had diagnosed cognitive impairments. The participant selection process was non-randomized and non-blinded.

The Rodi application was successfully installed and effectively employed for the study's objectives by 11 participants. Among these, 6 (54.5%) were female, and 5 (45.5%) were male. The participants' mean age was 60.8 years. The age range within the study varied from the oldest male participant aged 81 years to the youngest female participant aged 19 years (Table 1). Notably, participant distribution consisted of 1 individual aged 19 to 39 years (female), 4 individuals aged 40 to 59 years (1 male, 3 females), and 6 individuals aged over 60 years (4 males, 2 females). Regarding education, participants possessed an average of 12 years of education, spanning from 6 to 24 years (Table 1). Among the participants, 7 were currently employed or engaged in household responsibilities, while 4 male participants had retired. Among the retirees, the mean duration of retirement was 18.75 years, with a range of 8 to 25 years. Lastly, all participants lived with either family or friends. Notably, in terms of marital status, only the youngest participant was unmarried.

Table 1. Descriptive statistics: Age and years of education

	Minimum	Maximum	Mean	Std. Deviation
Age	19	81	60.82	18.137
Years of Education	6	24	11.45	6.832

3.2 Configuration of the RODI app

The RODI app has been meticulously designed to address cognitive domains aligned with the criteria for evaluating symptoms and interventions associated with neurocognitive disorders [23]. This app encompasses a broad spectrum of cognitive tasks, spanning complex attention, executive function, memory, learning, language, and perceptual-motor skills, with the goal of targeting various cognitive abilities, including attention, processing speed, feedback processing, working memory, mental flexibility, and problem-solving. The app includes a total of 10 cognitive tasks, with four of them featuring variations involving adjustments in answer formats or re-evaluation capabilities [24]. These tasks encompass functions such as integer recall, image or word identification, shape or colour selection, arithmetic calculations, and shape-colour matching, with task complexity modifiable through variations in the number of elements or intricacy [24]. Performance data is systematically captured and tracked over time, with task diversity ensured through the integration of random number generators to prevent repetitiveness. Developed for tablets and smartphones, the app provides two modes (Self-Assessment and Practice) with three difficulty levels (Easy, Medium, Difficult, and Mixed). Secure data collection is achieved through cloud storage integration via Firebase, ensuring user-generated content's safe storage and access while adhering to security regulations.

To cater to diverse users, a lighter app version has been configured, operating in practice mode without time constraints and displaying correct answers, serving individuals with varying cognitive statuses, including diagnosed impairments. Additionally, the app incorporates a digital consent process to ensure user awareness and agreement regarding the research's purpose, data usage, and anonymization. In summary, the RODI app's configurations facilitate varied and secure cognitive assessments, illustrating its potential for cognitive intervention and monitoring.

3.3 Administration and duration of the intervention

The first participant engaged with the RODI app for this study in October 2022, and the final participant's interaction occurred in December 2022. Participants were instructed to self-administer the RODI app two times per week, over a period of eight weeks. The data recorded by the application from each administration was automatically uploaded to Firebase Cloud Storage and subsequently downloaded and analyzed anonymously by the researcher. The initial two administrations of the RODI app by each user were regarded as educational sessions and were therefore excluded from the study analysis. As a result, data from 14 administrations per participant were subjected to analysis.

3.4 Data acquisition

During the administration of the RODI app, various aspects of the user's performance are recorded, including their choices and typed responses, whether those responses are correct or incorrect for each task. Additionally, the time taken by participants to respond to each task, as well as the time spent on both the exercise screen and the question-answer screen, are documented. The overall duration of completion and the total score for each administration are also recorded. The amassed dataset was uploaded to Firebase Cloud Storage and subsequently downloaded for further processing.

4 RESULTS

The achievable score range within the RODI app was from 5.4/15.0 to the maximum of 15.0/15.0. Regarding the administration time, the maximum duration noted during this study was 30 minutes, while the correspondingly minimum was 2.6 minutes. The mean duration time during the 1st administration of the application was 14.1 min and progressively decreased to 6.4 min during the 14th administration. Conversely, the mean value of the score exhibited an ascending trajectory, starting from 10.1/15.0 during the 1st administration and reaching 13.0/15.0 by the 14th. Graphs illustrating the scores per participant for all RODI app self-administrations are presented in Figure 2, while corresponding durations in minutes are depicted in Figure 3.

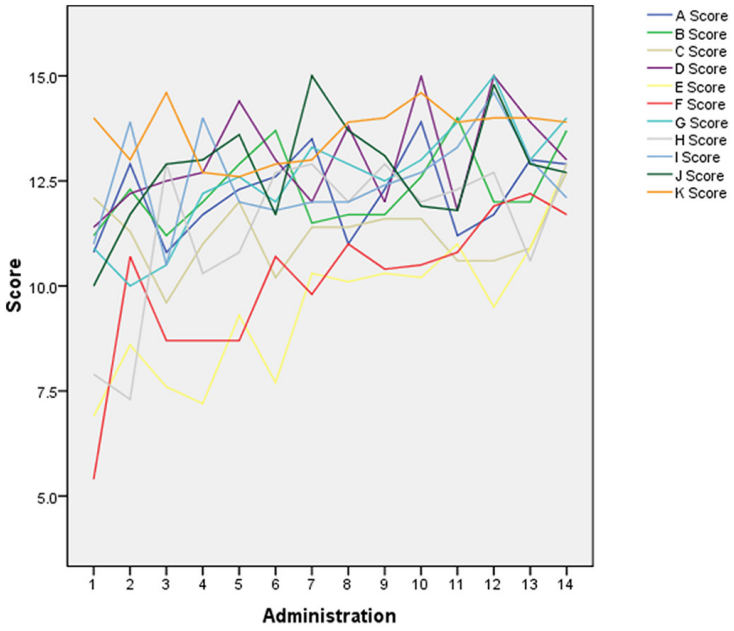


Fig. 2. Score per participant

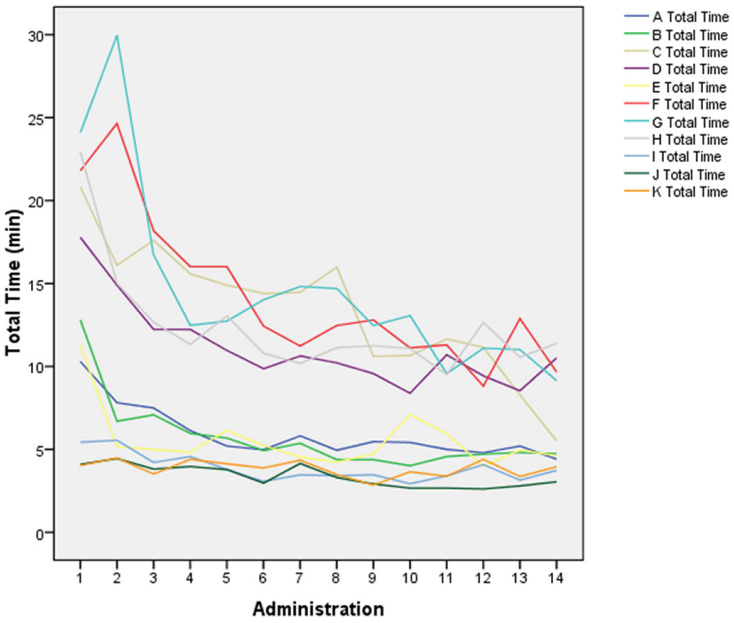


Fig. 3. Duration time (min) per participant

The analysis of participants' performance on the RODI app was undertaken to evaluate potential improvements resulting from their engagement with the application. To achieve this objective, Z scores were employed to facilitate a comparison of individual scores against the dataset's score distribution, irrespective of the original measurement scale. Figure 4 visually depicts a positive trajectory in mean performance, represented in Z scores with a mean of 0 and a standard deviation of 1, corresponding to the number of app administrations. Similarly, Figure 5 presents the trend of mean duration times, also represented in Z scores with a mean of 0 and a standard deviation of 1, in relation to the number of administrations. Notably, spanning 14 self-administrations, observable improvements were evident concerning both accuracy and response time. These improvements are substantiated by a significant progress in mean performance.

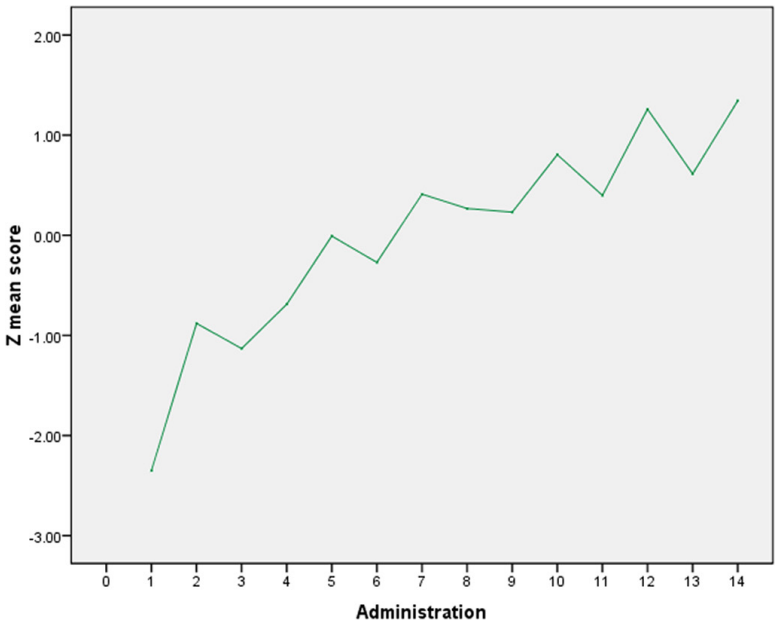


Fig. 4. Mean performance in Z scores, as a function of the number of administrations

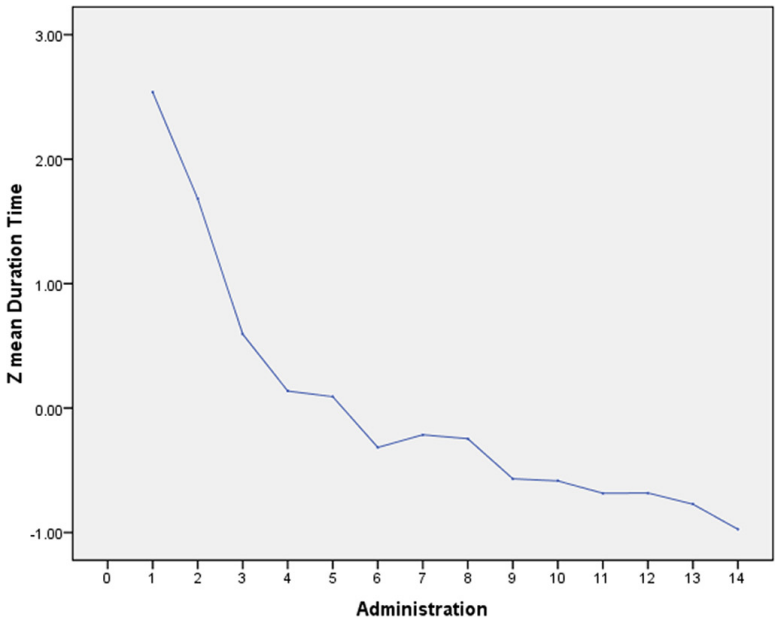


Fig. 5. Mean duration times in Z scores, as a function of the number of administrations

To comprehensively examine the impact of administration stages on participants' scores and session duration times as they engaged with the RODI app over time, a thorough and multifaceted analysis was conducted. This analysis involved a combination of analytical techniques, including ANOVA (Analysis of Variance) and subsequent post hoc t-tests with Bonferroni correction. To conduct the one-factor ANOVA, scores were meticulously selected from participants' initial and final self-administrations, as well as the mean values derived from administrations 2 to 13. The same selection was consistently applied to the duration times of the sessions.

Fig. 6. Profile plot, scores

The variation analysis by one factor with dependent samples exhibited a significant influence on participants' scores (F2, 20 = 15.23, p = 0.01, partial Eta squared = .604). The trajectory of average scores across administrations was illuminating, with initial, intermediate, and final average scores measuring 10.15, 12.0, and 12.96, respectively (Table 2). Post hoc comparisons, fortified by t-tests with Bonferroni correction, highlighted a statistically significant difference between the first and third measurement stages, as evidenced by a p-value of 0.01 (Figure 6).

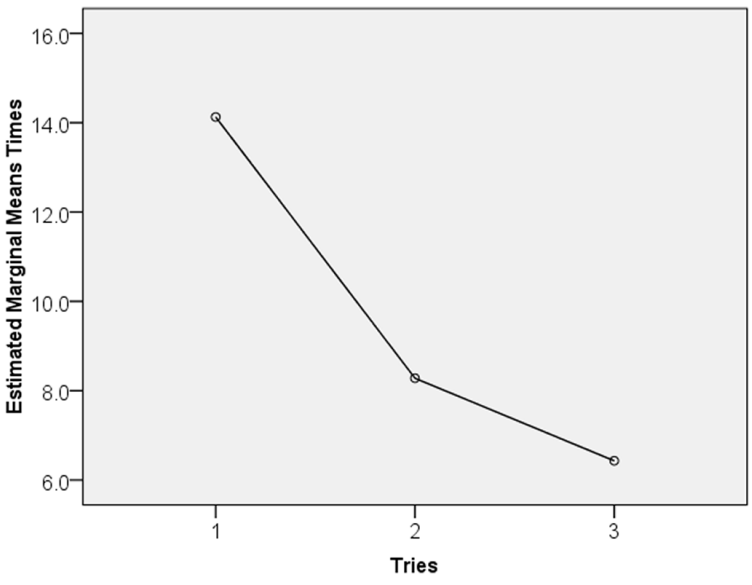


Fig. 7. Profile plot, scores

Furthermore, the single-factor variance analysis with dependent samples established a substantial impact on the duration time of administrations ($F_{1, 181} = 21.55$, $p < 0.01$, partial Eta squared = .683). The dynamic trend of mean duration times exhibited a progressive reduction from 14.13 minutes in the first session to 8.28 minutes in sessions 2 to 13, further decreasing to 6.43 minutes in the 14th session (Table 2). Significantly, the post hoc comparisons, bolstered by Bonferroni correction, brought to light statistically meaningful disparities between the initial and final measurement stages. Furthermore, these analyses unveiled notable distinctions between the first measurement and the mean value of administrations 2 to 13, with a p-value of less than 0.01 (Figure 7).

Table 2. Means and standard deviations of the three measurement stages (scores and duration time, 1st, 2nd to 13th, and 14th administrations)

Scores	Measurement Stages	Mean	SD
	1	10.15	2.474
	2–13	12.00	1.288
	14	12.96	0.706
Duration Times	**Measurement Stages**	**Mean**	**SD**
	1	14.13	7.724
	2–13	8.28	4.513
	14	6.43	3.082

Acknowledging the evident fluctuations in participants' performance demonstrated through Figures 2 and 3 during their interactions with the RODI app, a deliberate stratification of the participant cohort was performed. The division involved classifying participants into two distinct groups: those aged below 50 and those aged 50 and above. This analytical approach aimed to discern age-related effects on both performance and time efficiency within the context of the RODI app. For this purpose, the utilization of comparison graphs illustrating the average overall scores on the RODI app for the two age groups was selected.

In Figure 8, the comparative analysis of the average overall scores on the RODI app is depicted for the two age groups. It is noteworthy that both groups exhibited performance improvement over time. However, the rate of improvement for the younger age group was relatively slower compared to the older age group, a differentiation underscored by the computed R-squared (R^2) values: R^2 Linear $_{\text{over 50}} = 0.795$, R^2 Linear $_{\text{up to 50}} = 0.337$. Importantly, the younger age group exhibited an initial performance advantage of 1.86 points compared to their older counterparts, translating to approximately two additional correct tasks completed on the RODI app. Furthermore, the younger participants consistently maintained a higher average performance, except for a notable exception during the 14th and final administration, where the older group momentarily outperformed the younger cohort.

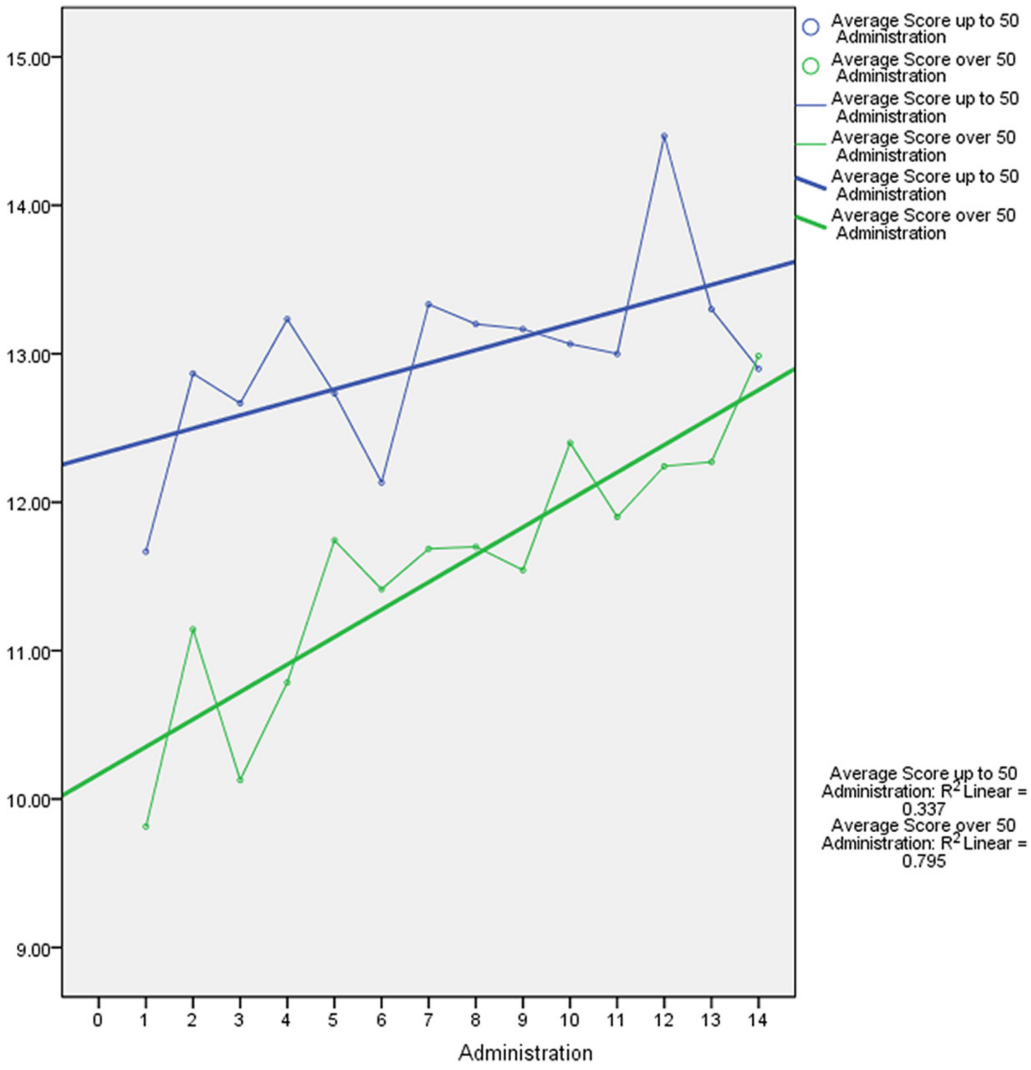


Fig. 8. Performance comparison graph of the two age groups

Turning attention to Figure 9, a similar comparison is presented, focusing on the duration time of RODI app self-administrations for the two age groups. Both groups demonstrated a reduction in the required time. Notably, the older age group exhibited a more pronounced rate of time reduction compared to the younger age group (R^2 Linear $_{\text{over 50}}$ = 0.741, R^2 Linear $_{\text{up to 50}}$ = 0.562). Remarkably, the younger age group demonstrated a considerably lower average duration time, starting nearly 13 minutes (13.21 min) earlier than the older group of participants. This difference persisted across all self-administration sessions, gradually diminishing to a disparity of 3.92 minutes.

Delving further into the dataset, a personalized analysis of each participant's performance was conducted, driven by the aim of assessing the potential of the application as a reliable cognitive performance monitor over an extended period. This investigation centered on evaluating individual performance solely within the last month, with the intent of minimizing the potential impact of participants' increasing familiarity with mobile technologies (device and application use) on their performance. To accomplish this, a targeted analytical approach encompassing descriptive analysis (Table 3), intraclass correlation coefficient (ICC) (Table 4), and control charts (Figure 10) of the scores were employed to effectively illustrate and comprehend participants' performance within this specific timeframe.

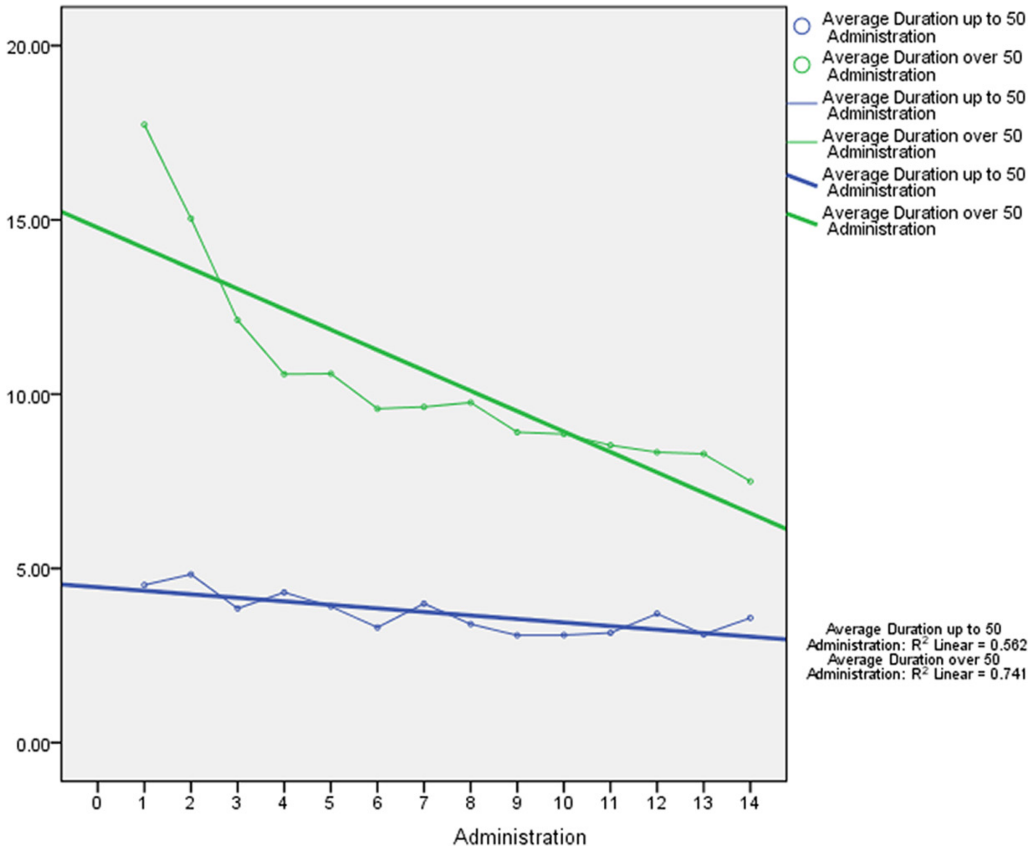


Fig. 9. Duration comparison graph of the two age groups

Examination of mean score values per participant unveiled significant variations, exemplified by Participant E achieving the lowest score of 10.65, while Participant K demonstrated the highest score of 14.6. This divergence was further elucidated through the evaluation of standard deviations, with Participant K displaying the lowest deviation of 0.43 and Participant D exhibiting the highest at 1.31 (Table 3).

In order to evaluate the consistency of scores across repeated administrations, the intraclass correlation coefficient (ICC) was calculated using a two-way mixed model effects analysis. The derived ICC value of 0.90 indicated strong test-retest reliability (Table 4), validating the consistency of scores over the specified period.

Finally, the utilization of control charts, based on participants' self-administration scores, facilitated the graphical representation of score progression across successive administrations. This approach was implemented to track potential fluctuations or trends within the process, offering valuable insights into the evolving nature of cognitive performance over time. The control charts revealed that the majority of processes operated within controlled variations, indicating predictable outcomes within control limits. A solitary exception emerged in Participant C's chart, where one data point during the last (14th) app administration surpassed the criterion of one point beyond the 3σ control limit, suggesting notably superior performance compared to the participant's average. Conversely, all other control charts demonstrated controlled variations, characterized by consistent and stable patterns of variation over time (Figure 10).

Table 3. Descriptive statistics of score per participant

Participant	Range	Min	Max	Mean	Std. Deviation	Variance
A	2.9	11.0	13.9	12.438	1.0663	1.137
B	2.5	11.5	14.0	12.400	.9562	.914
C	2.1	10.6	12.7	11.350	.6845	.469
D	3.2	11.8	15.0	13.312	1.3152	1.730
E	3.4	9.5	12.9	10.650	1.0226	1.046
F	2.4	9.8	12.2	11.038	.8297	.688
G	2.5	12.5	15.0	13.450	.8053	.649
H	2.3	10.6	12.9	12.288	.7846	.616
I	2.6	12.0	14.6	12.763	.8831	.780
J	3.2	11.8	15.0	13.238	1.1975	1.434
K	1.6	13.0	14.6	13.913	.4357	.190

Table 4. Intraclass correlation coefficient of the participants scores

	Intraclass Correlations	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.533b	.309	.795	10.478	10	70	.000
Average Measures	.901c	.782	.969	10.478	10	70	.000

5 DISCUSSION

The participants' performance was assessed within the app to explore potential improvements arising from the successive administrations of the RODI app. The Z-scores of participants' outcomes displayed a positive trend, encompassing both scores and duration times. This suggests that, on average, participants showcased improved cognitive performance alongside a growing proficiency in completing tasks within the app.

Thereafter, further analysis was performed using ANOVA and post hoc t-test with Bonferroni correction. ANOVA revealed a significant effect of administration stages on participants' scores, including the first, intermediate, and last measurements. The following post hoc comparisons demonstrated a substantial improvement in RODI app scores from the first administration to the last administration. Similar trends were noted when examining duration times, with the ANOVA revealing a notable impact of administrations on these time durations. Post hoc comparisons revealed significant differences between the first and last measurement stages, suggesting a decrease in duration times from the initial to the final administration. Moreover, significant differences were identified between the first measurement and the mean value of administrations 2 to 13, implying a reduction in duration times after the first administration. Acknowledging the fluctuations in participant performance while engaging with a cognitive training app, the research systematically categorized the participant cohort based on age, forming two distinct groups: those

below 50 and those aged 50 and above. The primary aim was to explore age's impact on cognitive performance and time efficiency within the app context.

The key findings unveil a consistent enhancement in cognitive performance within the app, evident through a progressive rise in mean scores across sessions for both age groups. This trend suggests favorable cognitive effects linked to the app's usage. An age-performance correlation was evident, with younger participants initially displaying higher mean scores, though this gap diminished over time. The analysis also demonstrated a convergence in performance between the two age groups, as evidenced by a narrowing range of mean scores. Significantly, in the 14th session, older participants outperformed their younger counterparts. Consistently, both age categories exhibited a trend of enhanced score performance coupled with shortened session durations. However, notable differences emerged between the two groups, with the older cohort demonstrating more substantial improvements in both performance aspects, encompassing scores and session durations, in contrast to the younger cohort.

Moreover, the R^2 values shed light on age's explanatory role in cognitive performance disparities. Notably, $R^2_{\text{Linear over 50}}$ indicates that roughly 79.5% of the variance in scores among those aged 50 and above can be attributed to age, and about 74.1% of the variance in duration time within this age group is age-related. In contrast, the influence of age on scores and duration time for those below 50 is relatively lower, indicated by $R^2_{\text{Linear up to 50}}$ (around 33.7% for scores and approximately 56.2% for duration time). This comparison underscores age's heightened influence on the older cohort while suggesting that other factors may contribute more to performance differences in the younger group. In conclusion, these observations emphasize the interplay of age, cognitive performance, and session duration during the utilization of the RODI app.

The combined analyses underscore the app's potential to enhance participants' cognitive performance and response times during tasks, aligning with findings from relevant studies [26]–[30] that also identified notable improvements in game performance measures. Similarly, the current study demonstrates an upward trajectory in cognitive performance and efficiency as participants engage with the app over time. This analysis affirms that progressive interaction with the app significantly enhances cognitive performance and efficiency within the tasks, evident through improved scores and duration times, highlighting its efficacy as a cognitive training tool.

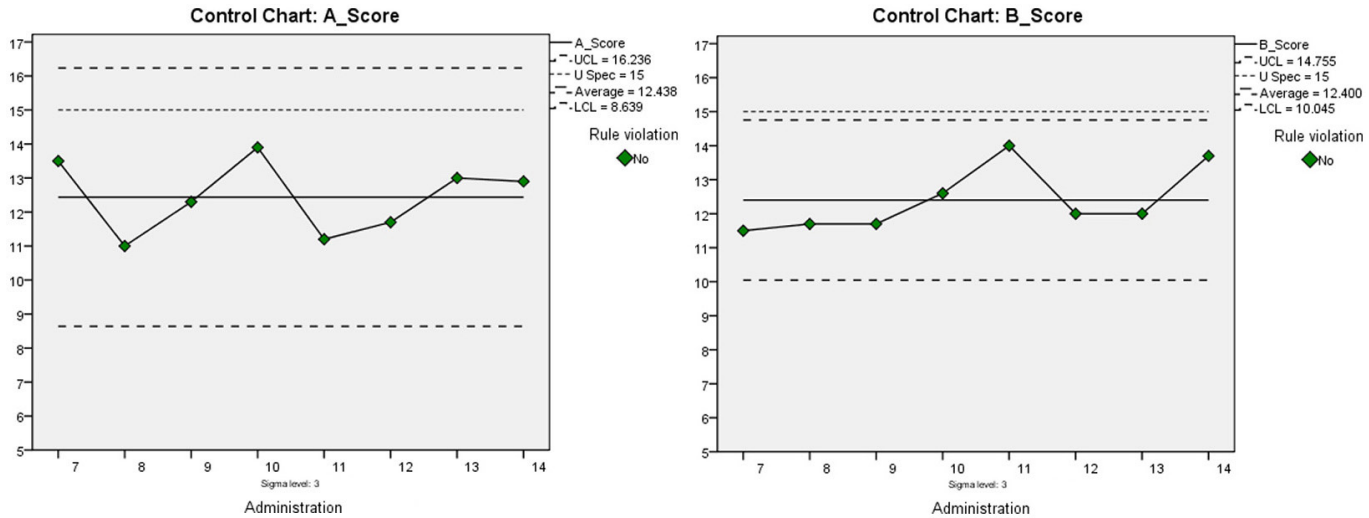
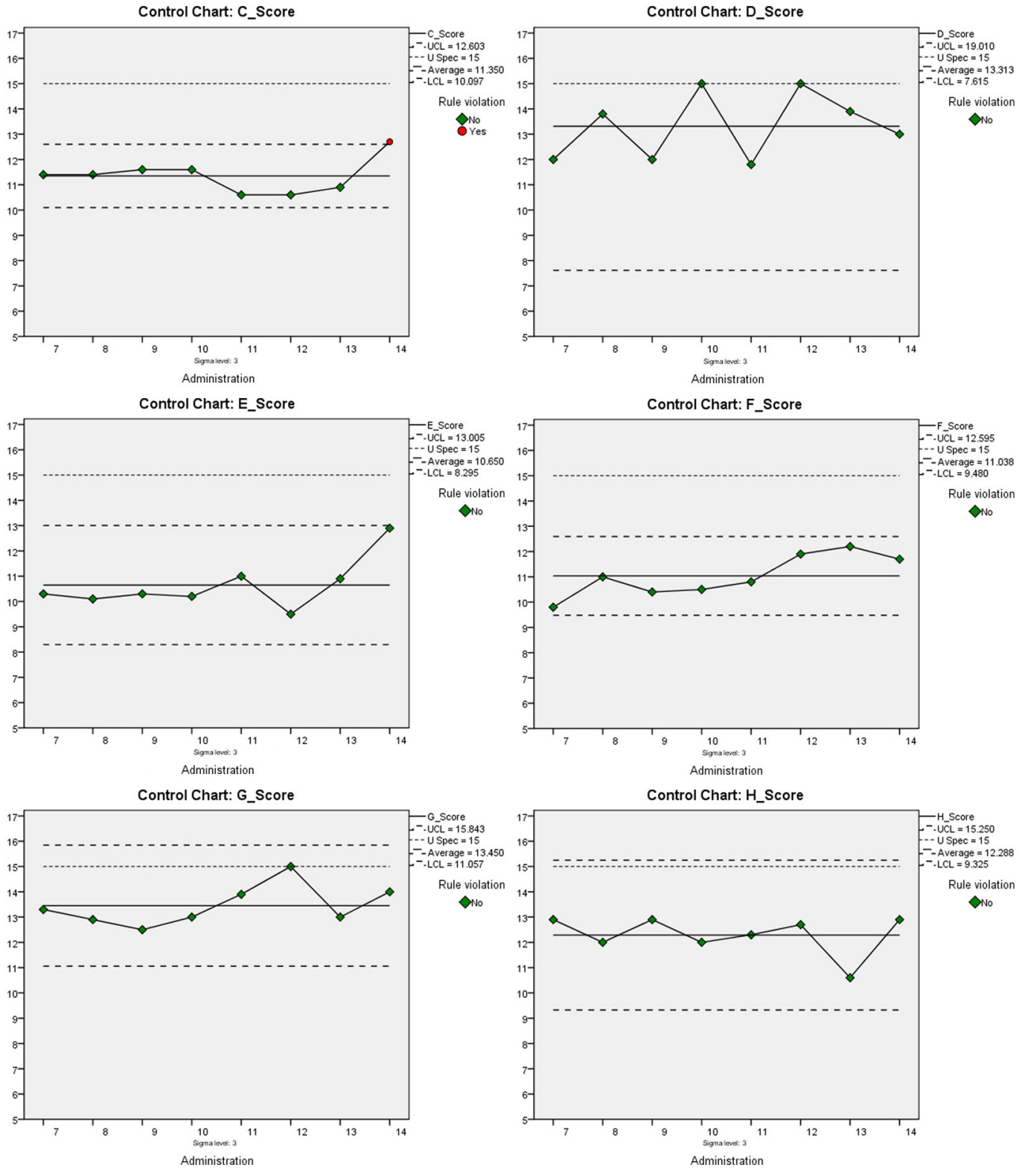


Fig. 10. *(Continued)*



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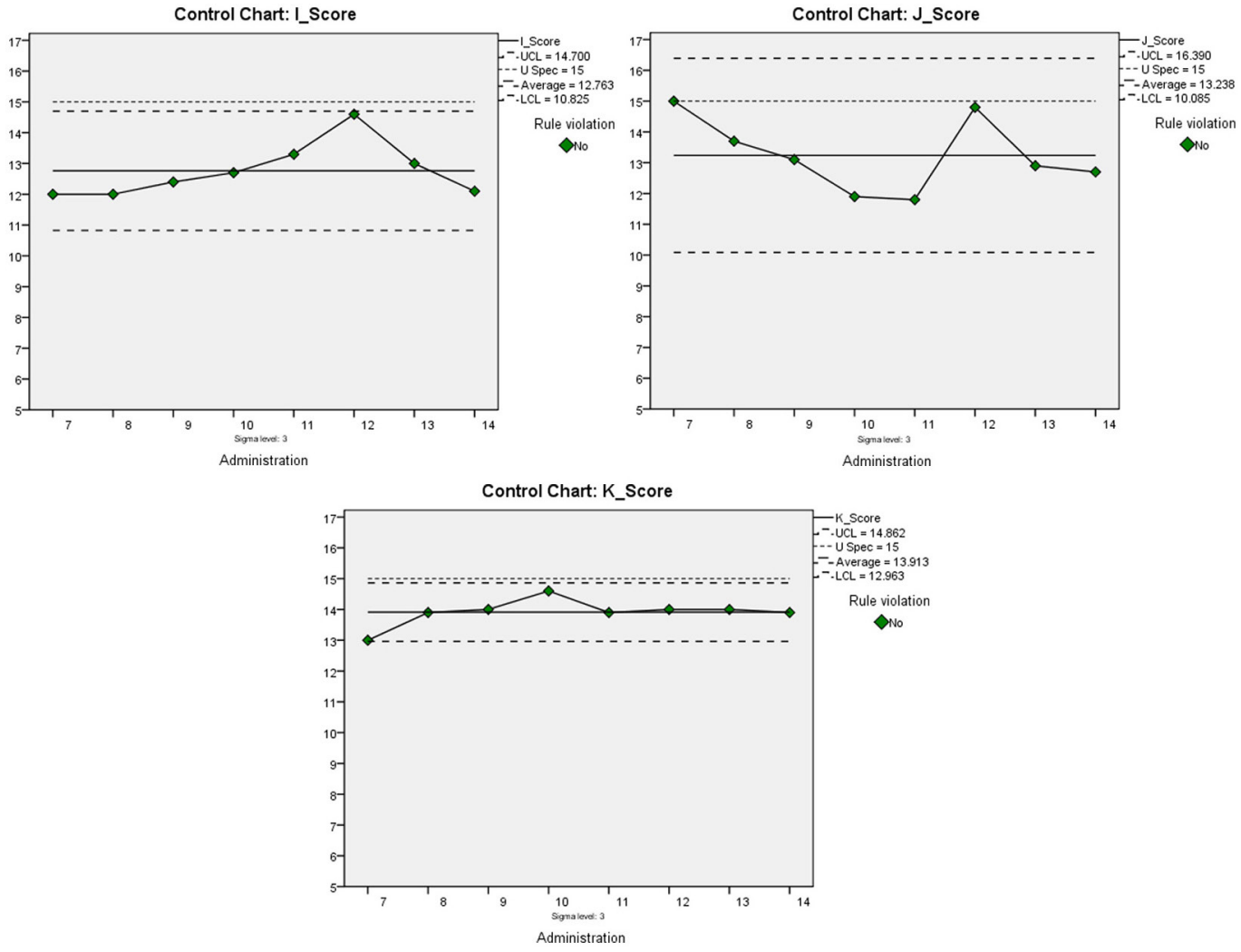

Fig. 10. Control charts per participant

Furthermore, the analysis outcomes also resonate with earlier research revealing younger individuals' superior accuracy and quicker responses in cognitive tasks [31]–[33]. This alignment is further supported by pertinent investigations [26]–[29], which additionally show enhancements in game metrics and age-related performance gaps favoring younger adults across cognitive measures [34], [35]. Furthermore, while a universally defined peak cognitive performance age remains elusive [36], [37], research suggests a continuous enhancement of cognitive knowledge until approximately age 50, followed by a potential decline [38]. This pattern aligns with the complex interaction between biological factors and the physical-social environment [39], [40], substantiating the age-related effects observed across the various cognitive domains targeted by the RODI application. This alignment is consistent with the divergent cognitive performance observed among different participant age groups.

The tasks integrated into the application possess inherent qualities that, when considered alongside alignment with previous research on cognitive training tools and brain plasticity [7]–[9], [27]–[29], evoke optimism regarding the potential of the RODI app to bring about substantial improvements. This positive outlook extends beyond the enhancements observed in the specific trained task, encompassing potential benefits in transfer tasks [41]. Such prospects are augmented by findings

that highlight the significance of digital devices as platforms for activities that stimulate cognition, thereby potentially delaying cognitive decline [42]. Furthermore, this sense of optimism applies not only to cognitively healthy adults but also to adults facing cognitive deficits [41]. The results obtained from participants with mild and major neurocognitive disorders reveal slight yet noteworthy distinctions in cognitive domain function tests and apathy [43]–[45]. However, it is noteworthy that these positive effects were specifically evident among participants who engaged with the app on a regular basis [45]. While previous literature and additional research on plasticity and the favorable impacts of cognitive training temper enthusiasm regarding the applicability of RODI [6]–[9], [46], substantiating these promising possibilities necessitates comprehensive further research involving a wider and more diverse cohort of participants. These observations collectively underscore the potential positive impact of the app on cognitive performance. The consistent improvement in both accuracy and response time aligns with the app's intended purpose of cognitive training and monitoring, suggesting the potential for enhancing cognitive performance over successive interactions.

Moreover, an observed trend of performance improvement is evident across 14 administrations of the RODI app for both age groups, illustrating an upward trajectory in their performance scores. However, a discernible discrepancy arises as the rate of improvement appears to be slower within the younger age group. This phenomenon may be attributed to several contributing factors, including the conceivable initial advantage held by the younger cohort, potentially leading to a performance plateau. Moreover, the increasing familiarity of the elderly with technology, mobile devices, and the app itself, coupled with the interplay of personality traits [47] and memory dynamics [48], could collectively shape these observed patterns. Furthermore, the analysis of the 14th administration of the RODI app unveils a noteworthy phenomenon that warrants deeper investigation. The temporary outperformance observed among the older age group during this final administration prompts inquiries into the dynamics of cognitive fluctuations throughout repeated interactions with the app. Aspects like engagement levels, task adherence, cognitive fatigue, external distractions, and motivational factors during this specific session could all play a role in contributing to this observed deviation. A comprehensive investigation of these factors could provide nuanced insights into the mechanisms behind cognitive variability across different administration stages, necessitating future in-depth research.

Successively, a focused evaluation of participants' individual performance was undertaken, with the aim of gauging the applicability of the application as a consistent cognitive performance monitor over an extended duration. In this targeted analysis, participants' performance was exclusively examined within the confines of the last month. Restricting the assessment to this timeframe was aimed both at mitigating the potential influence of heightened exposure to mobile devices, particularly for older participants who might have limited prior familiarity with such technology, as well as mitigating the accumulative impact of participants' overall experience with the Rodi application. The deliberate choice of the last month aspired to improve the credibility of the assessment by isolating the specific variables of interest, thus contributing to the robustness of the findings. The employed analytical methods, including descriptive analysis, intraclass correlation coefficient, and control charts effectively portrayed participants' performance within this specific timeframe.

The initial analysis of mean score values per participant revealed substantial variations, with participants exhibiting varying levels of performance consistency. The variation was further highlighted by the assessment of standard deviations. This diversity emphasizes the importance of examining individual performance trajectories.

The intraclass correlation coefficient, employed to evaluate measurement reliability and consistency over time, exhibited a robust value of 0.90, signifying strong test-retest reliability. This outcome validates the application's capacity to consistently gauge cognitive performance over the designated timeframe.

The utilization of control charts to visually represent participants' performance scores across successive app administrations served various functions, including systematic performance trend tracking, outlier and potential trend identification, providing a visual representation of performance shifts, and evaluating process stability. The majority of control charts exhibited controlled variations, signifying predictable outcomes within defined limits. An exception was observed in one participant's chart, where an outlier suggested notably superior performance during a specific administration. Conversely, the other control charts displayed stable and consistent patterns of variation over time.

In summary, this comprehensive analysis underscores the potential of the RODI app as a reliable tool for monitoring cognitive performance over extended durations. The robust ICC values and controlled variations within the control charts affirm the consistency and stability of performance measurements, bolstering the app's credibility in assessing cognitive performance changes over time.

6 CONCLUSION

The surge in the prevalence of mobile health applications and the integration of digital technologies for diagnosing and supporting individuals with cognitive disorders have garnered significant attention across research and commercial domains. Capturing these opportunities, the RODI app was meticulously developed to serve as a versatile mobile tool for process-based cognitive training, assessment, and performance monitoring across diverse cognitive domains. Designed to cater to both cognitively healthy older adults and those facing cognitive deficits, the app strives to provide a comprehensive and sustainable cognitive training experience within users' familiar environments, accessible whenever and wherever they desire.

The potential of the RODI app in cognitive training is substantial, as evidenced by consistent improvements in scores and response time. These outcomes seamlessly align with the app's fundamental goals of cognitive training and monitoring, suggesting its potential for cumulative cognitive enhancement through repeated interactions. Core strengths contributing to the app's efficacy include the ability to track individual performance trajectories, enabling personalized training plans that leverage users' strengths and areas for improvement. Continuous monitoring facilitates insight into cognitive changes, supporting effective progress tracking and adaptive training strategies. The app's focus on specific cognitive domains furthers targeted improvements, ensuring a holistic cognitive development approach.

Additionally, the app's provision of immediate feedback fuels motivation and engagement, while its potential to capture long-term cognitive trends offers a window into training efficacy and sustainability. The identification of outliers opens avenues for personalized interventions, responding dynamically to deviations from baseline performance. Especially pertinent for aging populations, RODI'S potential in monitoring cognitive health and its contribution to cognitive research showcase its versatile utility.

Importantly, the convenience offered by the app extends beyond its digital presence. It capitalizes on the convenience of space, time, and personalized intervention possibilities, allowing users to seamlessly integrate cognitive training and monitoring

into their daily routines. This flexibility not only enhances accessibility but also promotes consistent engagement, potentially leading to more effective outcomes. The app's ability to provide personalized interventions based on individual performance patterns adds an extra layer of convenience, tailoring the cognitive training experience to the specific needs and progress of each user. This multifaceted convenience, in conjunction with its versatile capabilities, positions the RODI app as a valuable and promising tool in the landscape of cognitive interventions.

The study's primary limitations include the utilization of a non-randomized and non-blinded approach for participant selection, a relatively small sample size, and a brief intervention duration. Additionally, the participants' characteristics are limited by the absence of significant sensory impairments or diagnosed cognitive impairment. Despite the promising findings from this study, further investigations are imperative to firmly establish the efficacy of the RODI app. It needs a thorough assessment as a cognitive training, evaluation, and monitoring tool. To validate the app's efficacy in improving cognitive function within a broader range of individuals, including those with varying levels of cognitive impairment, rigorous scientific investigations are imperative. Expanding the study population will provide invaluable insights for refining the app's effectiveness and tailoring it to accommodate diverse user requirements. Furthermore, longitudinal studies are essential for assessing the app's capacity to provide personalized cognitive training and monitor changes over an extended period, catering to individual needs.

Beyond the aforementioned perspectives, several other avenues for exploring the RODI app merit consideration. Exploring the app's complete version and analyzing the entirety of data collected by the app has the potential to yield valuable insights. Additionally, delving into the app's interaction with technological tools capable of providing digital and biological biomarkers could provide insightful information. The app's dual role as both a cognitive training intervention and a measurement tool underscores its promising value for future research endeavors.

To harness the full potential of the RODI app, future research should adopt diverse participant demographics, longitudinal designs, and comparative studies with other cognitive interventions. Neuroimaging correlations can shed light on underlying neural mechanisms, while investigating its efficacy for specific populations extends its applications. Refining personalization algorithms are pivotal for advancement. Exploring the trajectory of cognitive enhancement through the app and its real-world transfer effects is paramount. Collectively advancing research along these trajectories will enhance our comprehension of the app's contributions to cognitive well-being, enriching its practical implications and potential impact.

In conclusion, mobile-appropriate cognitive interventions offer a promising avenue to enhance screening and primary healthcare services, potentially mitigating the burden on healthcare systems [49], [50]. The integration of user-friendly apps with self-administered tasks facilitates wide-reaching screening and automated assessment while minimizing costs. However, further exploration is needed to effectively integrate these applications into healthcare systems and develop appropriate information policies [51]. While mobile devices allow remote assessment and training, the presence of clinicians for professional judgment and accurate diagnosis remains vital. These interventions can complement specialist visits by providing supplementary data on cognitive progress. Future research should focus on refining mobile interventions, ensuring smooth integration into healthcare systems and assessing their long-term impact on cognitive health and patient outcomes.

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9 AUTHORS

Panagiota Giannopoulou is a PhD candidate at the Department of Informatics, Ionian University, Corfu, Greece. She holds a Degree in Mathematics from the University of Patras, School of Natural Sciences, Department of Mathematics, and a Degree in Informatics from the Technological Educational Institute of Athens, Faculty of Technological Applications, Department of Informatics (E-mail: c16gian@ionio.gr).

Dr. Panayiotis Vlamos holds a BSc degree from the Dept. of Mathematics from the National and Kapodistrian University of Athens, and a PhD from the National Technical University of Athens. His research interests include Bioinformatics, Mathematical Modeling in neurodegenerative diseases, and neuroeducation. He is the Chairman of the Board of the Ionian University Research Center, Professor of Bioinformatics in the Bioinformatics and Human Electrophysiology Laboratory, Dept. of Informatics at Ionian University, Corfu, Greece (E-mail: vlamos@ionio.gr).

Mary-Angela Papalaskari is Associate Professor Emerita of Computing Sciences at Villanova University, 800 Lancaster Avenue, Villanova, PA 19085, USA, and a member of the Association of Computing Machinery (ACM) (E-mail: map@villanova.edu).