Development of a digital version of the Mini-Mental State Examination for children: a multidisciplinary study

Letícia Cardoso Mendonça Mustafá Awawdeh[1], Sandra Souza Rodrigues[1], Juliana Nunes Santos[1], Rosane Luzia de Souza Morais[2], Fernanda de Oliveira Ferreira[3], Evelyn Daynnara Miranda Corrêa[2], Ana Alice Aparecida Sales Pereira[2], Amanda Cristina Fernandes[4]

[1]Institute of Science, Technology and Innovation (ICTIN)
Federal University of Lavras (UFLA) – São Sebastião do Paraíso, MG – Brazil

[2]Federal University of Jequitinhonha and Mucuri Valleys (UFVJM)

[3]Federal University of Juiz de Fora (UFJF)

[4]Federal University of Minas Gerais (UFMG)

leticia.awawdeh@estudante.ufla.br, sandra.rodrigues@ufla.br
juliananunes@ufla.br, rosane.morais@ufvjm.edu.br,
fernanda.ferreira@ufjf.br, evelyn.miranda@ufvjm.edu.br
ana.sales@ufvjm.edu.br, amandacfernandes@ufmg.br

Abstract. ***Introduction****: Cognitive assessment of children is essential to identify deficits and plan appropriate interventions.* ***Objective:*** *This paper presents the development of a digital version of the Mini-Mental State Examination for Children (MMC), aiming to make it more accessible to children with motor impairments, such as those with cerebral palsy.* ***Methodology or Steps****: Using a simple lifecycle model (discovering requirements, designing alternatives, prototyping, and evaluating), a high-fidelity prototype was created.* ***Results:*** *Testing showed strong acceptance among healthcare professionals, with 100% considering the content appropriate and an average System Usability Scale (SUS) score of 85, indicating good usability. The digital version improves accessibility, reduces motor barriers, and enhances result standardization.*
Keywords *Mini-Mental State Examination, Children, Accessibility, Usability, Cognitive Tests.*

1. Introduction

Cognitive tests are essential for assessing mental abilities such as memory, attention, language, logical reasoning, and problem-solving. These instruments identify cognitive decline in clinical settings, particularly those associated with aging and neurological conditions. Over the years, several tools have been developed to assess cognitive status, each with specific characteristics regarding administration time, sensitivity, specificity, and target population. The Mini-Mental State Examination (MMSE) is one of the most widely adopted and validated instruments for cognitive decline. Developed by Folstein and McHugh in 1975 [Folstein et al. 1975], the MMSE provides a brief, structured, and standardized method for assessing cognitive function, especially in clinical and psychiatric settings. Its primary purpose is to assist health professionals in detecting cognitive impairment, monitoring changes over time, and supporting diagnostic decisions related to conditions such as dementia and delirium, particularly in older adults with cognitive and mental decline signs.

The MMSE assesses five cognitive function domains: temporal and spatial orientation, immediate and delayed memory, attention and concentration, language ability, and recall ability. The exam consists of simple tasks, such as naming objects, repeating sentences, and copying geometric figures. The total score ranges from 0 to 30, with higher scores indicating better cognitive performance. Each correct answer is awarded points, totaling up to 30. Scores above 24 are generally considered normal, while lower scores indicate different degrees of cognitive impairment (mild, moderate, or severe). The interpretation of results should consider the patient's level of education, language, and sociocultural background, as these factors may influence performance [Tombaugh e McIntyre 1992]. It is a method composed of 11 questions and takes only 5 to 10 minutes to be administered. Due to its ease of use, the MMSE has become an essential tool in clinical practice and scientific research. Its validity and reliability have been demonstrated in different populations [Mitchell 2009, Arevalo-Rodriguez et al. 2015].

A study by [Jain e Passi 2005] adapted and validated the MMSE for use with children in India, targeting an age group of 3 to 14 years old. The authors modified the original MMSE developed by [Folstein et al. 1975] for adults while maintaining the scoring structure to assess cognitive impairments in the pediatric population. In this sense, the Mini-Mental State Examination for Children (MMC) is a test that aims to provide brief and objective measures of children's cognitive functioning [Ibrahim et al. 2023]. It detects global or specific deficits in higher functions, such as memory, attention, and language. However, the MMC does not replace a complete neuropsychological evaluation with a full battery of tests and is only a predictor of cognitive problems. Based on these results, the professionals predict better treatment for those patients. Thus, the MMC screening test is easy to apply and correct and requires little time.

The MMC includes a total of 11 questions, was designed to be administered in approximately 5 to 10 minutes, and assesses six main cognitive domains: (1) orientation, (2) attention, (3) learning, (4) sensory perception—which requires motor coordination, (5) memory, and (6) language. It presents satisfactory results for each cognitive area and a table at the end according to age group. This structured adaptation offers a child-friendly alternative to the traditional MMSE, preserving its central diagnostic purpose while addressing developmental differences in younger individuals. The test should be administered appropriately (appropriate physical environment, child's conditions, correct instructions, etc.), and its interpretation should be made in light of the child's life history.

Although pediatric versions of the MMSE have been used in several countries, including Brazil [Andrade et al. 2011, Scarpa et al. 2017, Ibrahim et al. 2023] there are still limitations in its application to children with motor disabilities and communication difficulties, such as those with cerebral palsy and Autism Spectrum Disorder (ASD). The main difficulty is distinguishing between cognitive deficits and motor/linguistic limitations when applying the MMSE, especially in children with atypical development. Language-writing tasks, such as writing one's name or copying drawings, are especially challenging for these patients, and the lack of response in some tasks can be misinterpreted, confusing motor failure with cognitive failure. Furthermore, impaired handwriting due to cognitive impairment aggravates this issue [Balestrino et al. 2024]. Therefore, there is a significant gap regarding the effective and accurate application of the MMSE in pediatric populations with motor and communication difficulties. The lack of an accessible tool to overcome these limitations in the traditional MMSE hinders the assessment and early diagnosis of these cases.

This paper presented the development of a digital version of the MMC. We followed the Simple Lifecycle Model [Preece et al. 2023] to achieve this. This process involved an iterative approach that prioritized usability and accessibility so that the digital version of the MMC was functional and easy to use. We aimed to investigate the digital version as a screening tool for children with motor disabilities and difficulties in communication functions. By adapting the cognitive assessment process to a digital format, we aimed to overcome the physical limitations of handwriting and motor praxis while providing a more inclusive and accurate method for assessing children with cerebral palsy, ASD, and other related conditions. Through this development, we aimed to improve the accuracy of cognitive assessments and facilitate the integration of this tool into clinical practice for these specific populations.

This study is part of a project led by an interdisciplinary team of researchers from software engineering, speech-language pathology, physiotherapy, and psychology. The team results from a consolidated partnership between three institutions, including participants from Federal University of Lavras (UFLA), Federal University of the Jequitinhonha and Mucuri Valleys (UFVJM), Federal University of Juiz de Fora (UFJF), and Federal University of Minas Gerais (UFMG). It aims to integrate different perspectives in developing more inclusive technological solutions adapted to the needs of individuals with different types of cognitive and motor impairments. This interdisciplinary approach is related to Grand Challenge 3. Plurality and Decoloniality of the Grand Research Challenges in Human-Computer Interaction in Brazil for 2025-2035 (GranDIHC-BR 2025-2035 - GC3: Plurality and Decoloniality in HCI) [de Oliveira et al. 2024], which highlights the importance of addressing plurality and decoloniality in the field of Human-Computer Interaction (HCI). By bringing together professionals from different areas of knowledge, this study sought to integrate technological and clinical practices, promote a research environment that values approaches centered on different points of view, and construct more inclusive interactive systems.

Despite the relevance of inclusive design in HCI, few studies have proposed or evaluated digital adaptations of pediatric cognitive tests that address the dual challenge of motor and communication impairments. This study contributes to closing this gap by integrating principles of inclusive interaction design with clinical assessment, aligned with the GC3 of GranDIHC-BR [de Oliveira et al. 2024], which emphasizes the importance of an approach that addresses the complexity and diversity of the Brazilian context.

The structure of the paper is organized as follows: Section 2 outlines the ethical procedures followed during the development of this research. Section 3 overviews the key related works. Section 4 describes the methodology adopted for developing the digital version of the MMC. Section 5 details the evaluation process of the digital version, describing the two evaluations that were carried out and the results. The conclusions and directions for future work are outlined in Section 6.

2. Ethical Issues

This research was approved by the Research Ethics Committee of the responsible institution under the study protocol CAAE: 85892524.0.0000.5148. All participants provided written informed consent before the start of the research activities. The consent included detailed information about the objectives of the study, methodology, risks and benefits involved, and voluntary participation. We ensured that the participants understood their participation was optional and voluntary, and that they could withdraw from the study without prejudice.

We kept all data collected anonymously to guarantee privacy and confidentiality. Unique codes replaced personal identifiers to ensure no personal information was disclosed in the text or during data analysis. Information regarding the participants was kept by the provisions of the General Personal Data Protection Law (LGPD), Law No. 13.709 (2018)[1], ensuring the protection of personal data during its processing and storage.

Participants were recruited based on the desired profile for the study, and we took all measures to ensure non-discrimination and inclusion of children under specific conditions related to the research. Thus, this study was conducted in full ethical compliance, aiming to guarantee respect for the rights and dignity of participants, with special attention to data protection and guaranteeing anonymity at all stages of the research.

3. Related Work

The development of a digital version of the MMC emerges as a necessary response to the limitations of the traditional administration of the test, particularly for children with severe motor impairments, such as those diagnosed with cerebral palsy. Although the MMC is a valuable tool for screening cognitive impairments in childhood and demonstrates good prognostic capabilities [Cainelli et al. 2020], significant accessibility barriers hinder its practical application.

A study conducted by [Ricardo et al. 2017] demonstrated that children with severe forms of cerebral palsy, such as spastic quadriplegia, often score zero on the MMC, not due to cognitive deficits, but rather due to their inability to perform motor tasks. This limitation compromises the validity of the results and makes it difficult to distinguish between motor and cognitive impairments. [Ricardo et al. 2017] also emphasizes the need for adapted assessment tools to ensure fairer evaluations and more appropriate interventions for this population.

In contrast, the digitization of cognitive assessments has seen considerable progress in adult populations. The Mini-Mental State Examination (MMSE) has been applied successfully in telemedicine contexts [Ciemins et al. 2009]. The [MoCA Test Inc. 2024] Montreal Cognitive Assessment (MoCA), one of the most widely used tools for detecting mild cognitive impairment, already features a digital version (MoCA 2.0) accessible via tablets and suitable for both clinical

[1] `https://bit.ly/4cXjqQk`

and home settings [MoCA Test Inc. 2024]. Another example is the M-CogScore, a validated digital tool designed for rapid and remote cognitive screening, demonstrating performance comparable to the MMSE and allowing for unsupervised application [Alim-Marvasti et al. 2022]. More recently, [Chen et al. 2024] developed a fully automated model for administering the MMSE, leveraging computational algorithms to expand the possibilities of remote cognitive screening further.

Although these tools represent technological advances, most are directed toward adults and do not address the unique interaction needs of children with motor or communication impairments. Even widely used platforms for pediatric cognitive assessment, such as CANTAB and the NIH Toolbox, lack adaptations for motor accessibility. CANTAB, for example, offers non-verbal, tablet-based tasks for children and adolescents but assumes fine motor skills, making it unsuitable for users with motor deficits [Luciana e Nelson 2002]. Similarly, the NIH Toolbox provides validated cognitive measures for children as young as three, but does not offer interaction alternatives for those with physical limitations [Zelazo et al. 2013]. In most cases, these tools also require supervised administration and are limited in their ability to separate motor performance from cognitive ability, an essential distinction in children with cerebral palsy.

In this context, developing a digital version of the MMC represents a technological advancement and an ethical and clinical imperative. An interactive format accommodating motor limitations can enable more accurate and equitable assessments, particularly for vulnerable populations. This approach broadens the instrument's applicability across clinical, educational, and home environments, fostering more reliable diagnoses and effective interventions.

The study by [de Souza et al. 2021] highlights the challenges and complexities surrounding the inclusion and adaptation of individuals with cerebral palsy, emphasizing the need for in-depth and essential research. The study points out that efforts toward inclusion and understanding such individuals directly impact their lives and those around them regarding healthcare and more inclusive education. With technological advancements in this field, individuals with cerebral palsy may experience improved inclusion in society, as well as enhanced treatments and diagnoses that contribute to a better quality of life.

Additionally, regarding children with ASD, the work conducted by [Soppa Geremias et al. 2024]. Demonstrated the effectiveness of the game "Pensar e Vestir" ("Think and Dress"), which helps children with ASD learn to choose appropriate clothing based on the weather. This highlights the potential of the MMC to support children with ASD by assisting healthcare professionals in better understanding each child's spectrum and enabling them to plan more tailored treatments. It also contributes to improving children's computational thinking skills.

Although several digital tools for cognitive assessment have been developed, most are directed toward adult populations and do not address the unique interaction needs of children with motor impairments. For instance, digital versions of the MoCA [MoCA Test Inc. 2024] and M-CogScore offer remote and unsupervised assessments but are not designed for children and do not incorporate motor accessibility features.

Similarly, while the game Pensar e Vestir demonstrates the effectiveness of digital tools for children with ASD, its focus is educational and not diagnostic. Some pediatric-oriented tools, such as the CANTAB battery and the NIH Toolbox, provide robust cognitive evaluations for children and adolescents. Still, they assume preserved motor abilities and require responses through delicate touch or timed selections, making them less suitable for children with conditions like cerebral palsy. These platforms also do not offer mechanisms to dissociate cognitive limitations from motor execution issues, a critical distinction in this population. In contrast, our proposal targets explicitly the pediatric population with cerebral palsy and ASD, combining principles of inclusive interaction design and clinical validity. It restructures motor-dependent tasks using alternative input methods (e.g., simplified touch, verbal guidance) without compromising the original cognitive constructs. By addressing this dual challenge—cognitive assessment and motor accessibility—our system fills a critical gap not covered by existing tools.

Therefore, developing a digital version of the MMC has been shown to support education, the healthcare professional's confidence in treatment approaches, and the child's engagement in the process. This allows those close to the child to understand their cognitive development better and whether progress is being made. In the long term, children with ASD or mild cerebral palsy may gain a degree of autonomy in various aspects of their daily lives.

4. The Digital Version of the MMC

The digital version of the MMC was developed based on the Simple Lifecycle Model described by Preece et al. [Preece et al. 2023] and presented in Figure 1. The development process included discovering requirements, designing alternatives, prototyping, and evaluating, resulting in the final version of the MMC. As proposed by the model, the steps did not follow a rigid and sequential order; there were continuous iterations, with the development of the digital version of the MMC occurring incrementally. The steps were carried out in collaboration with the project team through brainstorming sessions. In addition, the design was created by professionals from different areas. This work involved an interdisciplinary team formed by researchers from software engineering, speech-language pathology, physiotherapy, and psychology.

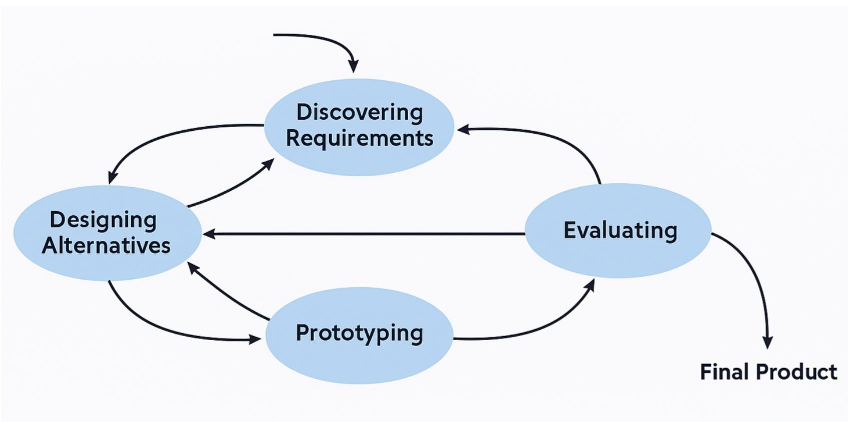


Figure 1. Iterative process diagram with five steps: discover requirements, design alternatives, prototype, evaluate, and generate the final product.

We recorded all the brainstorming sessions. We documented each session's discussions and decisions and made them available in an online repository[2] for reference. Below, we detail each of the development activities and the results.

4.1. Discovering Requirements

The discovery requirements activity aims to explore the problem space and clearly define what will be developed, including understanding the target users and how the product can benefit the users' lives [Preece et al. 2023]. In this research, we obtained this understanding through the study of the MMC and the brainstorming sessions conducted with a speech therapist, three physical therapists, and a psychologist. We performed the sub-activities of gathering, analyzing, specifying, and validating requirements. First, two profiles of actors who would use the system were identified:

- Health professionals, such as psychologists, speech therapists, etc., with experience in cognitive assessments. They administer the MMC, adjust it according to the children's needs, and interpret the results for diagnosis and intervention.
- Children (3-14 years old) with different types of cognitive and motor impairment, including cerebral palsy and ASD. The main users interact with the test to assess their cognitive performance.

We held three biweekly brainstorming sessions from June to July 2024. The sessions lasted an average of 1 hour, were recorded, and later transcribed using the Whisper tool[3]. Afterward, we analyzed the transcripts and prepared a requirements document available in an online repository[4]. The main Functional Requirements (FR) and Non-functional Requirements (NFRs) are presented below, which were later validated by the project's interdisciplinary team of researchers through low-fidelity prototypes. Table 1 shows the list of validated FRs, and Table 2 shows the NFRs.

ID	Description
FR01	The system must collect personal data and record the location, date and time of the test application.
FR02	The interface must use colors appropriate to the age group, avoiding excess information and visual elements.
FR03	The system must present figures and allow open responses by touch or typing, in a dynamic and interactive way.
FR04	The system should allow digital marking of responses and touch interaction with large buttons for children with motor difficulties.
FR05	The system should allow naming activities, command sequences and drawing of geometric shapes, with complexity adjusted to age.
FR06	The system should record and validate the patient's responses, generating a report and providing friendly and discreet feedback during the test.

Table 1. Six functional requirements of the system, listing the identifier (FR01 to FR06) and descriptions about data collection, accessible interface, interactivity, motor support, cognitive activities and report generation.

[2]https://bit.ly/4lWV7WC
[3]https://openai.com/index/whisper
[4]https://bit.ly/requirements_document_MMC

ID	Description
NFR01	The interface must be simple, visual and intuitive, making it easy for children aged 3 to 14 to use without relying on complex reading.
NFR02	The system must be accessible to children with motor and cognitive disabilities, with audio, visual feedback and compliance with WCAG 2.2 criteria (1.2.1 to 4.1.3).
NFR03	The system must work fully on Android tablets and mobile phones, with a responsive interface and accessible touch for children.

Table 2. Non-functional system requirements.

4.2. Designing Alternatives

After defining the essential requirements of the digital version of the MMC, we started brainstorming sessions to generate design alternatives. During the sessions, we created a screen map (see Figure 2) to help organize the design alternatives. To do this, we used the MMC execution sequence as a reference to implement it in digital format. In addition, we had to consider the main limitations of the users who would answer the test. Consequently, we implemented functions to accommodate specific motor skills and verbalization limitations. These functions include alternative questions adapted to the limitations while maintaining the same objectives as the questions in the original test. Based on the screen map (see Figure 2), we established the correct sequence of questions to be used.

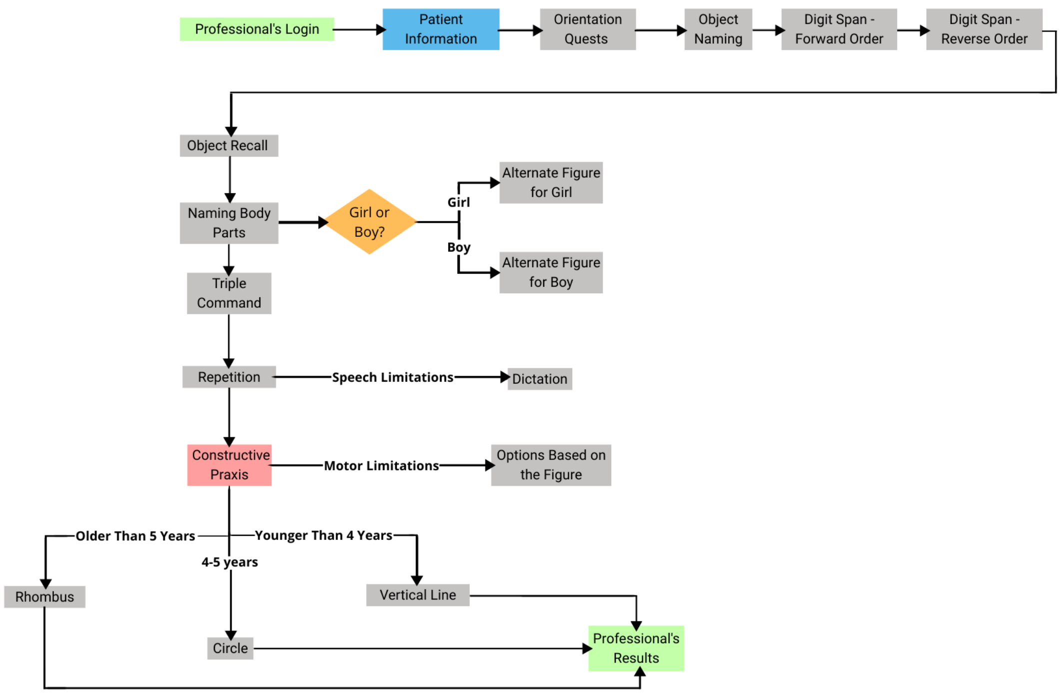


Figure 2. Screen mapping flowchart after brainstorming sessions, with navigation paths connecting different interface elements, including alternative pages, input limitations, and age options, organized hierarchically from top to bottom.

Based on neuropsychology questions, the initially closed-ended questions had to be removed to prevent the user from being influenced in their responses. Consequently, for the digital version of MMC to be inclusive for children with cerebral palsy, revalidation of the MMC would be necessary to ensure the test's objectives could be achieved without excessive effort.

4.3. Prototyping

Prototypes are concrete representations of the design that allow stakeholders to interact. They aim to assess the solution's suitability to the identified needs [Preece et al. 2023]. About the degree of detail and realism with which the prototype represents the final solution, prototypes are classified as low, medium, and high fidelity. Low-fidelity prototypes are generally applied in the early stages of development, helping to design and validate ideas quickly and economically. High-fidelity prototypes, however, are more similar to the final product, including more refined visual and functional details [Preece et al. 2023].

We used the Figma tool[5] to create low and high-fidelity prototypes for this activity. The low-fidelity prototype consisted of images representing the MMC questions, focusing on the visual elements and information organization, as seen in Figure 3. This prototype was presented and validated with the interdisciplinary team of researchers during a brainstorming session. The aim was to explore design alternatives and ideas to facilitate the application of MMC with children.

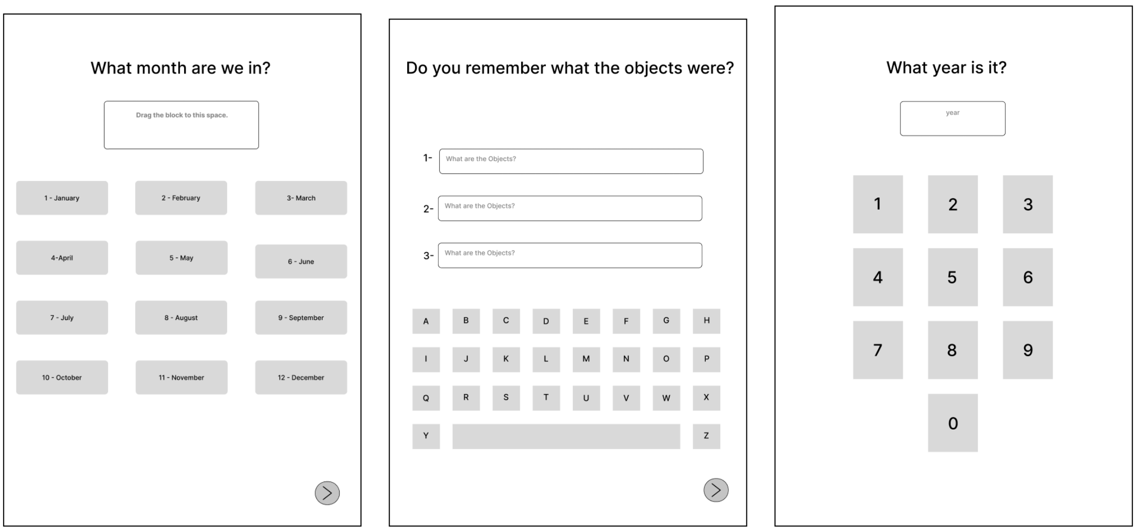


Figure 3. Three low-fidelity prototype screens.

[5]`https://www.figma.com/pt-br`

After refinements based on feedback from the interdisciplinary team of researchers, we created the high-fidelity prototype with changes in guidance questions since it was proposed in the low-fidelity prototype that the children would only have to click. However, this would not be possible with the psychological bias because if we kept the questions closed, we would induce the answer. Therefore, we modified all the screens of the guidance questions, and a keyboard was added so that the children could type the answers they wanted without being induced to do so.

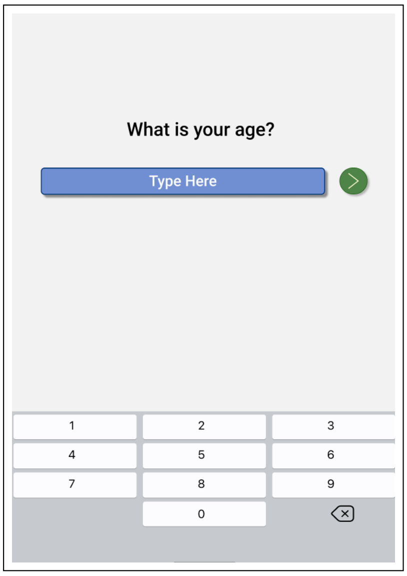
Finally, after making changes based on the feedback received and creating a high-fidelity prototype, more meetings were held to validate the digital version of the MMC and ensure compliance with the functional and non-functional requirements. More changes were suggested and accepted, such as changing the triple command screen to improve optimization and eliminate the need to drag to leave the correct sequence. There was also a color change to make it more eye-catching for children. Another change was in the number entry so that the healthcare professional knows how many numbers to enter without having to check whether or not they have moved on to the next step.

4.4. The digital version

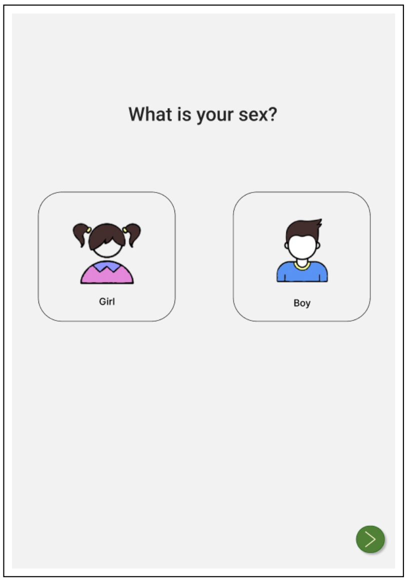
The digital version of the MMC aims to support both children with cerebral palsy and ASD in performing the MMC in an accessible manner, as well as assist healthcare professionals in better understanding the patient and gaining confidence in their diagnosis and in the treatment and intervention strategies that can improve the patient's quality of life. We developed the high-fidelity prototype, assuming a healthcare professional would accompany the child during the MMC performance. In this context, the professional would observe the specific tasks where the child experiences difficulties and better analyze the patient's behavior to understand their cognitive functioning during this testing phase.

The digital version of the MMC was created using Figma tool. We chose this tool due to its ease of customization and prototyping capabilities. Despite certain limitations, Figma proved to be a suitable option, especially considering that the MMC is intended for mobile devices such as tablets, which are commonly used in clinics where this type of test is conducted.

After professionals on the low-fidelity prototype conducted the analysis, feedback was collected, and necessary adjustments were identified, leading to the development of the high-fidelity prototype. In this version, we used visually appealing colors to engage children (e.g., green for proceeding, blue for information input areas), for example, in the Figure 4a screen and in Figure 4b screen, aiming to create visual emphasis. However, as previously discussed, the MMC is not intended for children to perform the test independently. Instead, it is designed to be used with the presence and supervision of a healthcare professional. For this reason, the interface includes substantial textual content intended to be read aloud by the professional in conjunction with the evaluation form, guiding the child through the current screen's task.



(a) Orientation question age screen



(b) Orientation question sex screen

Figure 4. Two screens of a digital version of the MMC.

With this in mind, the MMC included mandatory requirements for easy accessibility for children with disabilities. As a result, the high-fidelity prototype avoids abrupt movements since some children with cerebral palsy may lack fine motor coordination, making adaptations necessary in certain areas. However, due to the neuropsychological nature of the test, some elements (such as orientation) could not be modified, considering that making the test more accessible would require a complete revalidation of the original instrument.

It was observed that the high-fidelity prototype lacks responsiveness and user feedback, primarily due to the limitations of the tool used. Optimization issues were also encountered, given the large number of screens and the underlying logic, especially in the keyboard component. The keyboard required complex logic to be fully functional, including features such as a delete key and specific logic for the first version of the triple-command question.

The first version of the triple-command question required the child to drag the figure according to the number shown in the second column. However, implementing this interaction in Figma demanded complex logic, which resulted in constructing a flow tree consisting of 103 screens in total for the triple command question (Figure 5). Consequently, the prototype frequently crashed at this point, often displaying a white screen. To address this issue, we implemented an alternative logic: instead of dragging, the selected sequence number is displayed when the user clicks on a figure. This change significantly improved the prototype's performance and optimization, as shown in Figure 6.

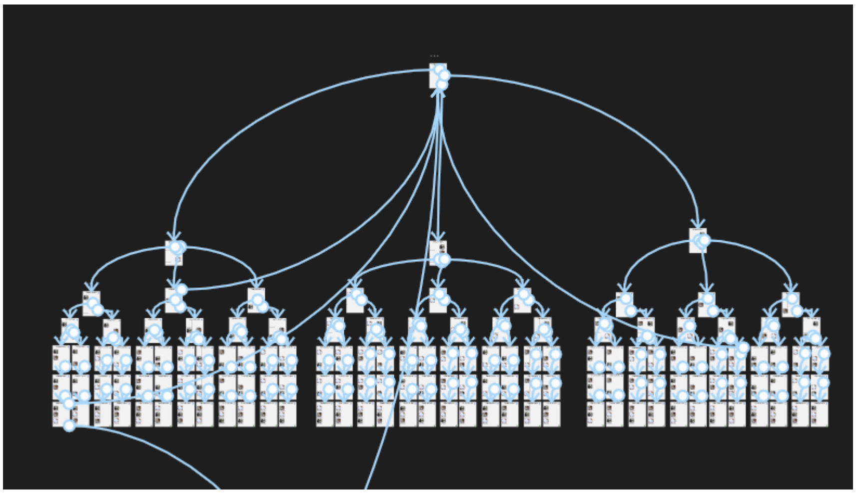


Figure 5. A non-optimized version of the triple command, demonstrating the logic behind the functional prototype in the triple command section.

Figure 6. Triple-command question with sequential images of a child picking up paper, folding it, and placing it on the floor, instructing the user to click in the correct order.

Furthermore, during the practical use of the high-fidelity prototype, it became evident that Figma is not one of the most suitable tools for use with inexperienced users, such as children without an adult assisting them. This is especially true given that children are generally accustomed to responsive behavior when interacting with mobile applications, leading some to pause on specific screens, expecting such responsiveness. As a result, the high-fidelity prototype does not yet fully meet all the requirements due to the tool's limitations in its development.

5. Evaluating of the Digital Version of the MMC

After the high-fidelity prototype was developed, it was evaluated, consisting of the last Simple Design process activity [Preece et al. 2023]. The planning, execution of the study, and analysis of the evaluations were based on the DECIDE framework proposed by [Preece et al. 2002]. This is a framework to guide evaluation and provides a checklist to help plan evaluation studies. It has six iteratively related items that were defined as follows in our study [Preece et al. 2002]:

- **D - Determine evaluation objectives:** Identify usability issues in the prototype interface; assess the system's efficiency, effectiveness, and user satisfaction during interaction; and gather user feedback to inform improvements to the interface and the overall user experience.
- **E - Explore key evaluation questions:**
  - What are the main points of frustration or barriers users encounter in the interface?
  - Does the current design meet the defined usability requirements?
  - How do users perceive and rate their overall satisfaction with the system?
- **C - Choose appropriate evaluation methods:** Employ a usability questionnaire and the System Usability Scale (SUS) to assess the prototype from the perspective of healthcare professionals. We will also conduct Heuristic evaluations with usability experts to identify interface design issues.
- **I - Identify and manage practical aspects of the evaluation:** Record the test sessions using audio, video, and photographs to support later analysis.
- **D - Decide how to address ethical considerations:** Ensure all participants provide informed consent through a formal consent form before the evaluation.
- **E - Evaluate, interpret, and present the results:** Analyze the collected data using basic descriptive statistics and SUS scores to summarize usability findings.

In this context, the high-fidelity prototype of the MMC underwent two evaluations: the evaluation with health professionals and the heuristic evaluation. The details of these evaluations and their results are presented below.

5.1. Evaluation with health professionals

The first evaluation we conducted was with healthcare professionals. This study aimed to evaluate the high-fidelity prototype of the MMC with users who will administer the tests to children. The evaluation sought to verify the functional consistency of the system in supporting the application of the test and to analyze aspects related to the clarity, usefulness, relevance, and ease of use of the interface based on the perception of experts and users in the field.

Physiotherapy, speech therapy, and psychology professionals were invited to participate in this study. This participant profile was chosen to collect relevant data, considering their experience as specialists and users who will apply the MMC test to children. The selection was conducted through convenience sampling [Yin 2015], which was characterized as non-probabilistic, considering the availability of participants. It is essential to highlight that this evaluation is a case study, and this approach focuses on the in-depth exploration of the object of study, involving a limited number of participants

[Lazar et al. 2017]. Thus, the limitations regarding the generalization of the results are recognized, given that the sample does not have statistical significance.

Initially, to achieve the evaluation objective, we conducted a pilot test to validate the evaluation protocol. After making all necessary corrections, we invited 30 professionals who use MMC to participate in the evaluation. This evaluation was conducted remotely and consisted of signing the consent form and completing an online questionnaire[6] that contained the link to access the prototype. The questionnaire was prepared using the Google Forms tool[7]. It consisted of questions related to the profile of the evaluators, open and closed questions aimed at evaluating the prototype in addition to the ten questions of the System Usability Scale (SUS) questionnaire [Brooke et al. 1996]. Additionally, a field was made available so that health professionals could record observations and additional considerations about the prototype.

Ten health professionals with experience in child assessment and intervention participated in this study stage. However, only nine responses were considered valid, and one was disregarded because it was inconsistent with the purpose of the questionnaire. Based on the responses collected from the questionnaire, the data was exported to a spreadsheet, and the SUS scoring [Sauro e Lewis 2016] formula was applied. This calculation consists of subtracting one from the score for odd-numbered questions (response - 1) and subtracting the response from 5 for even-numbered questions (5 - response). All resulting values are then summed, and the total is multiplied by 2.5 to obtain the final score, where values above 68 are generally considered above average in terms of usability [Sauro e Lewis 2016].

The majority (90%) held postgraduate degrees. All participants reported familiarity with the MMSE, and 80% had used or currently use the instrument in pediatric evaluations. Concerning the prototype, 100% of the participants agreed that the wording of the test questions was clear and objective and that the content was aligned with the goals of the MMC. Furthermore, 89% considered the illustrative images clear and appropriate, and 79% positively evaluated the design elements, such as colors, fonts, and layout, as suitable and appealing for the target population. Most professionals (89%) acknowledged the digital version's potential as a valuable tool in clinical practice, endorsing its application for assessing cognitive functioning in children. This can be seen from the following comments:

> *"I have already applied the Mini-Mental Physical to more than 200 children, and I like this digital option. Today's children are very used to technology; in addition to being more practical and economical, it does not generate waste. It is also easier to generate a result.(Professional 1)"*

> *"I congratulate those involved. Some improvements can be made: the images of the item corresponding to folding the paper are somewhat similar,..... Other than that, I found it consistent! The idea is excellent; keep up the goal. Congratulations!(Professional 2)"*

> *"Useful for research and remote care. (Professional 6)"*

[6] https://bit.ly/42QtdEh
[7] https://docs.google.com/forms

“Congratulations on the initiative. It will be beneficial, especially for children with cognitive impairment who need easy visual stimuli. (Professional 8)"

“First of all, congratulations on the initiative! An excellent work and idea. I loved it, and it will facilitate and help a lot in clinical practice and research. Congratulations to everyone involved! It will be a success, for sure! (Professional 9)"

As the final question in the questionnaire, we asked participants to provide comments/suggestions, or criticisms about the MMC prototype. The leading suggestions for improvement included improving the visual appeal of the images and incorporating feedback mechanisms for children during the tasks. We will consider these recommendations in the next version of the prototype.

Sequentially, we performed the analyses using the scale of [Sauro e Lewis 2016] for the questions related to the SUS. The results of the SUS questionnaire, detailed for each of the 10 questions answered by the nine participants (Px), are presented in Table 3.

Questions	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**
Answer P1	5	1	5	2	5	1	5	1	5	1
Answer P2	5	2	3	1	4	2	4	5	5	2
Answer P3	4	1	3	2	3	5	5	3	4	1
Answer P4	4	2	4	4	3	2	4	2	4	2
Answer P5	4	2	4	1	5	1	5	1	5	1
Answer P6	5	1	3	1	2	2	4	1	4	1
Answer P7	4	1	5	3	5	1	4	1	4	1
Answer P8	5	1	5	4	5	2	5	1	5	1
Answer P9	4	1	5	1	5	1	5	1	4	1
Average	4	1	4	2	4	1	4	1	4	1

Table 3. Responses of nine participants (P1 to P9) to a questionnaire with 10 questions (Q1 to Q10). Each response is on a scale of 1 to 5, where 1 represents the lowest score and 5 the highest. With the average of the responses in the end.

Odd-numbered questions: (4-1)+(4-1)+(4-1)+(4-1)+(4-1)=3+3+3+3+3=15

Even-numbered questions: (5-1)+(5-2)+(5-1)+(5-1)+(5-1)= 4+3+4+4+4 = 19

Sum of questions * 2,5 = 15 + 19 = 34 * 2.5 = 85

Score SUS = 85 – **Rating:** A+

The SUS score was calculated based on the average of the responses from the nine participants. As can be seen from the calculations above, the results obtained in the SUS questionnaire, with a total score of 85, indicate that the prototype presented excellent usability. The SUS scale ranges from 0 to 100, and a score higher than 68 is considered positive [Sauro e Lewis 2016]. Thus, the value of 85 is well above this limit and suggests that, in general, the participants evaluated the experience of using the system as satisfactory. This score suggests the perception of an effective, efficient, and easy-to-use system that meets users' needs.

Analyzing the odd and even questions of the SUS reveals a balanced distribution of responses among the participants. The score of the odd questions, which mainly address the general perception of the system and positive aspects of use, was 15, while the even questions, which focus on the negative aspects of use, totaled 19. This balance in the responses may indicate that, although the system was generally well received, it also presented challenges in aspects related to clarity or comprehension in some points, as seen in the scores of the even questions. Even so, the total score for the even-numbered questions is still high, which shows that most participants found the system relatively easy to understand and interact with.

When analyzing the individual responses from each participant (P1 to P9), the evaluation was relatively consistent, with a range of scores from 1 to 5. The distribution of responses indicates that participants had varied experiences with the prototype, with some areas being particularly well evaluated, while others may have generated more difficulties. This is expected in usability testing, where users may have different levels of familiarity with the system and its functionalities [Nielsen 1993, Rubin e Chisnell 2008]. Although the average score is high, observing individual responses can provide valuable information to identify areas that could be improved.

While the SUS's overall score of 85 is excellent, analyzing individual responses reveals that specific areas could be improved, particularly in complexity, clarity, and interaction with the system. The majority of participants had a positive experience. Still, the more challenging areas of usability, such as interface clarity and ease of interaction, should be reviewed to ensure that the system is intuitive and accessible to all users, regardless of their level of familiarity with technology. Adjustments in these areas could further improve the user experience. Still, they could also help raise the SUS's score in future evaluations, making the MMC prototype even more effective and enjoyable.

Therefore, the results obtained from the evaluation with users who will apply the tests to children indicate that the prototype developed satisfactorily meets the objectives proposed in the study. The SUS score of 85, assigned by health professionals, demonstrates that the MMC prototype has an excellent level of usability and is suitable for clinical use. This result provides objective evidence that the developed solution is functional, simple, and accessible, directly aligning with the objectives proposed in this study. The high acceptance by professionals reinforces the tool's potential as a digital screening instrument for children with motor limitations and communication difficulties. In addition, the data obtained reinforce that the digital adaptation of the cognitive assessment process helps to overcome the limitations of handwriting and motor praxis, offering a more inclusive, accurate, and suitable method for clinical practice with children with cerebral palsy, ASD, and similar conditions.

5.2. Heuristic Evaluation

The Heuristic Evaluation (HE) [Nielsen e Molich 1990, Nielsen 1994b] was performed to identify usability problems and barriers in the high-fidelity prototype of the MMC. The HE was conducted by four experts, two Ph.D. professors, and two master's professors. They all have more than five years of experience in usability and conduct research in this area. The sample size was defined based on the study by [Nielsen 1992], which recommends that between three and five evaluators be used to obtain a significant number of usability problems.

The experts performed the HE by examining the interfaces of the digital version of the MMC and judging its compliance with Nielsen's heuristics [Nielsen 1994a] described in Table 4. To do this, we provided instructions inviting the evaluator to read and sign the consent form. In addition, the evaluator had to answer a questionnaire about their profile. Afterward, we invited each evaluator to perform the HE individually following a scenario, which is described below:

> *During a session at the Physiotherapy School Clinic, a 4-year-old child with mild cerebral palsy is accompanied by a physiotherapist to apply the Mini-Mental State Examination in the digital version, using a tablet. After the professional logs in and registers the child, the examination begins. The child interacts by touching the screen to select objects, order image sequences, and identify body parts in illustrated figures without writing. Visual and auditory prompts help with task comprehension, while the system provides positive feedback for each completed step. At the end, an automatic summary of the score and areas of attention is presented to the professional, highlighting the results and suggesting possible interventions.*

Thus, for each problem found, each expert indicated its location in the interface, assigned a severity level, and described the violated heuristics and possible solutions. We recorded all this information in a spreadsheet made available to them. All experts met remotely, reviewed the problems identified in the individual evaluations, and created a consolidated report. The evaluations lasted 30 days in February 2025, each lasting approximately 40 minutes.

Table 4 and Figure 7 summarize the distribution of usability violations identified in the prototype based on the heuristics proposed by [Nielsen 1994a]. The analysis reveals that heuristic H4 – Consistency and standards presented the highest number of violations (n = 8), suggesting visual inconsistencies that may compromise the predictability of the interface. Heuristics H1 – Visibility of system status and H5 – Error prevention also stood out with five occurrences each, evidencing deficiencies in communicating system status to the user and implementing mechanisms to prevent operational errors. In summary, the experts pointed out problems related to the visual inconsistency of recurring elements, such as misaligned navigation controls and variations in text formatting (H4); the absence of progress indicators and clear information about the current stage of the process (H1); and the lack of validation of mandatory fields and the ambiguity in the filling instructions (H5), highlighting the need for adjustments to the interface design to ensure a more predictable, transparent, and safe user experience.

Nielsen's heuristics	**Number of violations**
H1 -Visibility of system status	5
H2 - Match between system and the real world	1
H3 - User control and freedom	3
H4 - Consistency and standards	8
H5 - Error prevention	5
H6 - Recognition rather than recall	1
H7 - Flexibility and efficiency of use	1
H8 - Aesthetic and minimalist design	3
H9 - Help users recognize, diagnose, and recover from errors	1
H10 - Help and documentation	1
Total of violations	**29**

Table 4. Table showing the number of violations of the 10 Nielsen heuristics found in the prototype, totaling 29 problems, with emphasis on "Consistency and standards" (8 violations).

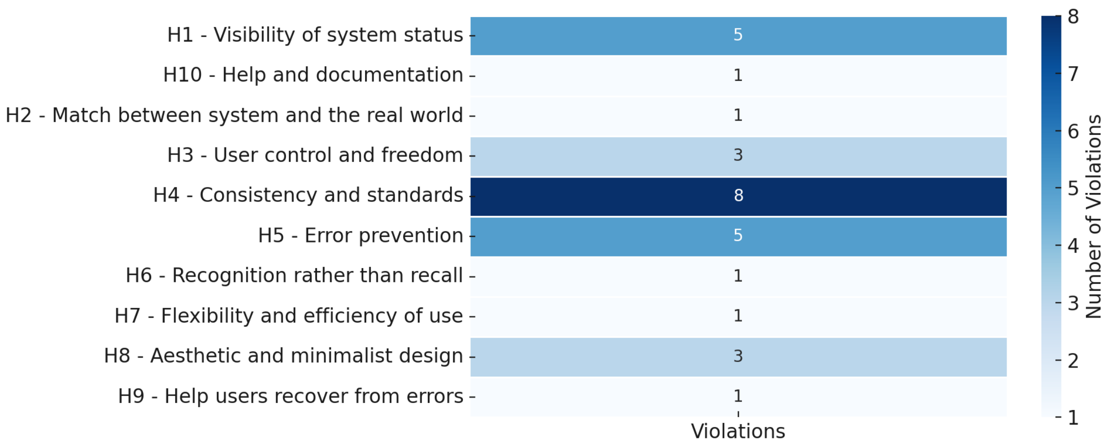


Figure 7. Number of violations of Nielsen's heuristics in the prototype, highlighting heuristic H4 (Consistency and patterns) with 8 violations as the most recurrent.

Although the results obtained so far are promising, it is essential to recognize that the current version of the prototype still has limitations regarding accessibility. The prototype was evaluated by health professionals and usability experts, which allowed an initial assessment of its usability and clinical applicability. However, for the solution to be considered effectively accessible, additional improvements are needed to enhance consistency and interaction patterns. In addition, conducting evaluations with end users and children with motor and communication disabilities is essential to validate its practical applicability and inclusive potential. As part of our future work, we will conduct tests with children in clinical and educational settings, with the support of health professionals. We will also conduct accessibility evaluations with experts to validate the non-functional requirements defined in the solution design. These steps are essential to revalidate and refine the digital version of the MMC, guaranteeing its inclusive potential and confirming its effectiveness as a digital tool to support the neurocognitive assessment of children with cerebral palsy, ASD, and other related conditions.

6. Conclusion and Future Work

The objective of this study was the development of a digital version of the MMC to enable children with certain types of limitations to complete the test, aiming to support healthcare professionals in achieving greater accuracy and safety in diagnosis and treatment, as well as increasing the satisfaction of the children undergoing the test. The proposed approach was developed based on the Simple Lifecycle Model [Preece et al. 2002] and evaluated for health professionals with the SUS questionnaire and Heuristic Evaluation with usability experts, allowing for an initial assessment of the effectiveness and applicability of the digital version of MMC.

The results obtained indicate that the usability of the digital version of the MMC is high (score SUS=85) and that healthcare professionals would use the final product. This suggests that the research is promising regarding the digitization of the cognitive test, thus opening up possibilities for better understanding the cognitive abilities of children with greater limitations, such as those with cerebral palsy and ASD. Furthermore, the qualitative analysis reinforces the solution's potential for use in rehabilitation clinics and schools.

This study's main contribution lies in providing a digital alternative for the MMC and in demonstrating that interaction design principles can be effectively applied to transform traditionally motor-dependent cognitive tasks into inclusive digital experiences. This work advances the state-of-the-art by offering evidence that inclusive interfaces for children with CP and ASD can preserve test validity, support healthcare workflows, and foster equitable access to neurocognitive diagnostics. These findings contribute directly to the research agenda of inclusive HCI and assistive technologies.

For future work, we propose to improve the prototype and conduct evaluations with children with disabilities to observe how the team can revalidate the MMC. In addition, we will also conduct evaluations with accessibility experts to verify the non-functional accessibility requirements we defined for the system (Table 2). Additional functionalities are also suggested, such as a help button for cases where the child cannot complete a task in the standard way and automatically generate a cognitive status report immediately after the test is completed. This report could include visualizations, such as graphs, to illustrate the patient's progress (for example, whether they improved with the applied intervention). It is also essential to recognize the limitations of the tool used to build the current prototype, particularly regarding optimization and responsiveness. Therefore, future work should incorporate user feedback and adopt a development tool with fewer performance and usability restrictions.

7. Acknowledgments

Thanks for my mom for supporting me in my studies and believing in me. Thanks for Sandra Rodrigues and Juliana Santos for believing in my potential for this project and guiding me in my academic life. We also thank all our volunteers (health professionals and usability experts) for their willingness to participate in this research and thank the resources of the Federal University of Lavras.

References

Alim-Marvasti, A., Kuleindiren, N., Harvey, K., Ciocca, M., Lin, A., Selim, H., Houlden, H., Chan, D., e Nachev, P. (2022). Validation of a rapid remote digital test for impaired cognition using clinical dementia rating and mini-mental state examination: An observational research study. *Frontiers in Digital Health*, 4:1029810.

Andrade, P., Oliveira Ferreira, F., Vasconcelos, A., Lima, P., e Haase, V. (2011). Cognitive profile, motor deficits and influence of facilitators for rehabilitation of children with neurological dysfunction. *Revista Paulista de Pediatria*, 29(3):320–327.

Arevalo-Rodriguez, I., Smailagic, N., Roqué i Figuls, M., Ciapponi, A., Sanchez-Perez, E., Giannakou, A., e Cullum, S. (2015). Mini-Mental State Examination (MMSE) for the detection of Alzheimer's disease and other dementias in people with mild cognitive impairment (MCI). *Cochrane Database of Systematic Reviews*, 2015(3):CD010783.

Balestrino, M., Brugnolo, A., Girtler, N., Pardini, M., Rizzetto, C., Alì, P., Cocito, L., e Schiavetti, I. (2024). Cognitive impairment assessment through handwriting (cogitat) score: a novel tool that predicts cognitive state from handwriting for forensic and clinical applications. *Frontiers in Psychology*, 28(15):1275315.

Brooke, J. et al. (1996). Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7.

Cainelli, E., Giacomo, D. L. D., Mantegazza, G., Vedovelli, L., Favaro, J., e Boniver, C. (2020). Prognostic role of Mini-Mental State Pediatric Examination (MMSPE) on neuropsychological functioning. *Neurological Sciences*, 41(3):619–623.

Chen, L., Zhang, M., Yu, W., et al. (2024). A fully automated mini-mental state examination assessment model using computer algorithms for cognitive screening. *Journal of Alzheimer's Disease*, 97(4):1661–1672.

Ciemins, E. L., Holloway, B., Coon, P. J., McClosky-Armstrong, T., e Min, S.-J. (2009). Telemedicine and the mini-mental state examination: assessment from a distance. *Telemedicine and e-Health*, 15(5):476–478.

de Oliveira, L. C., Amaral, M. A. a., Bim, S. A., Valença, G., Almeida, L. D. A., Salgado, L. C. d. C., Gasparini, I., e da Silva, C. B. R. (2024). GranDIHC-BR 2025-2035 - GC3: Plurality and Decoloniality in HCI. In *Proceedings of the XXIII Brazilian Symposium on Human Factors in Computing Systems*, IHC '24, New York, NY, USA. Association for Computing Machinery.

de Souza, R. L. M., de Freitas, C. R. S., Freire, A. P., e Delabrida, S. (2021). Enabling the use of photography equipment by people with upper limb disabilities: a participatory design case study of a wearable assistive technology prototype. In *Proceedings of the XX Brazilian Symposium on Human Factors in Computing Systems*, IHC '21, New York, NY, USA. Association for Computing Machinery.

Folstein, M. F., Folstein, S. E., e McHugh, P. R. (1975). "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12(3):189–198.

Ibrahim, B. A., Hussein, S. A., e Abdullah, W. H. (2023). Cognitive functions in children with type i diabetes. *Wiadomości Lekarskie (Medical Advances)*, 76(5):944–950. Original Article.

Jain, M. e Passi, G. R. (2005). Assessment of a modified mini-mental scale for cognitive functions in children. *Indian Pediatrics*, 42(9):907–912. Clinical Trial; Validation Study.

Lazar, J., Feng, J. H., e Hochheiser, H. (2017). *Research Methods in Human-Computer Interaction*. Morgan Kaufmann, Cambridge, MA, 2 edition.

Luciana, M. e Nelson, C. A. (2002). Assessment of neuropsychological function through use of the cambridge neuropsychological testing automated battery: Performance in 4- to 12-year-old children. *Developmental Neuropsychology*, 22(3):595–624. PMID: 12661972.

Mitchell, A. J. (2009). A meta-analysis of the accuracy of the mmse in the detection of dementia and mci. *International Psychogeriatrics*, 21(4):689–702.

MoCA Test Inc. (2024). Montreal Cognitive Assessment (MoCA). `https://mocacognition.com`. Acessado em: 8 de maio de 2025.

Nielsen, J. (1992). Finding usability problems through heuristic evaluation. CHI '92, page 373–380, New York, NY, USA. Association for Computing Machinery.

Nielsen, J. (1993). *Usability Engineering*. Morgan Kaufmann, San Francisco, CA. 1st edition.

Nielsen, J. (1994a). Enhancing the explanatory power of usability heuristics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '94, page 152–158, New York, NY, USA. Association for Computing Machinery.

Nielsen, J. (1994b). *Heuristic Evaluation*, page 25–62. John Wiley & Sons, Inc., USA.

Nielsen, J. e Molich, R. (1990). Heuristic evaluation of user interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '90, page 249–256, New York, NY, USA. Association for Computing Machinery.

Preece, J., Rogers, Y., e Sharp, H. (2002). *Interaction Design: Beyond Human-Computer Interaction*. John Wiley & Sons, New York, NY, 1 edition.

Preece, J., Sharp, H., e Rogers, Y. (2023). *Interaction Design: Beyond Human-Computer Interaction*. John Wiley & Sons, Hoboken, NJ, 6 edition.

Ricardo, M., Oliveira, A. P. M., Bueno, F. P. L., Oliveira, F. F., de Souza, S. L., Santos, C. M. R., e Geraldi, H. V. (2017). Mini-mental state exam for children (MMC) in children with hemiplegic cerebral palsy. *Dementia & Neuropsychologia*, 11:287–296.

Rubin, J. e Chisnell, D. (2008). *Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests*. Wiley Publishing, Inc., Indianapolis, IN, 2 edition.

Sauro, J. e Lewis, J. R. (2016). *Quantifying the User Experience: Practical Statistics for User Research*. Morgan Kaufmann, Waltham, MA, 2 edition.

Scarpa, P., Toraldo, A., Peviani, V., e Bottini, G. (2017). Let's cut it short: Italian standardization of the MMSPE (Mini-Mental State Pediatric Examination), a brief cognitive screening tool for school-age children. *Neurological Sciences*, 38(1):157–162.

Soppa Geremias, M., Cerigueli Dutra, T., Maschio, E., e Gasparini, I. (2024). Computational thinking development in children both neurotypical and with intellectual disabilities by the game "pensar e vestir". In *Proceedings of the XXII Brazilian Symposium on Human Factors in Computing Systems*, IHC '23, New York, NY, USA. Association for Computing Machinery.

Tombaugh, T. N. e McIntyre, N. J. (1992). The mini-mental state examination: A comprehensive review. *Journal of the American Geriatrics Society*, 40(9):922–935.

Yin, R. K. (2015). *Estudo de Caso: Planejamento e Métodos*. Bookman Editora, Porto Alegre, RS, 5 edition. Tradução da 5ª edição norte-americana.

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., e Weintraub, S. (2013). II. NIH Toolbox Cognition Battery (CB): Measuring executive function and attention. *Monographs of the society for research in child development*, 78(4):16–33.