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VALID Care Pathways: A Framework for Meaningful Digital Platform Design

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This manuscript underwent peer review. It was received 09/05/2023 and was with the authors for 16 months for two revisions. Blooma John served as Associate Editor.



VALID Care Pathways: A Framework for Meaningful Digital Platform Design

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Abstract:

Despite the advancement in design, development, and use of digital platforms in general, data-driven platforms and novel use of emerging technologies in healthcare, in particular, have been lagging behind. Sleep is one of the fundamental pillars of health and the cognitive functioning connected to sleep deprivation has, to date, not been researched to a large extent. Moreover, cognitive functioning is usually measured in an in-laboratory setting, although digital measuring at-home would be beneficial. Thus, digitally measuring cognitive functioning over an extended period of time can provide valuable insights into sleep health. Based on findings from a two-year action design research project, dimensions of the design and development of a digital platform to deliver at-home measuring of cognitive functioning were explored. The digital platform was designed with the primary objective of achieving high usability while preserving the validity of relevant clinical measurements. The main contribution of this paper consists of conceptualizing and theorizing care pathways through digital platforms based on our novel findings from co-designing and evaluating the platform with professionals and 55 participants, leading to the formulation of VALID framework to inform the ongoing design and development process of digital platforms of the future.

Keywords: Action Design Research, Healthcare IS, Health Information Technology, Digital Care Pathways.

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1 Introduction

Emerging technologies have driven recent advances in the digitalization of healthcare systems worldwide. However, when compared to the overall digitalization of society, the healthcare sector still lags significantly behind (Hochwarter et al., 2022; Ellingsen & Monteiro, 2012; Monteiro et al., 2013; Fitzgerald & Russo, 2005; Fitzpatrick & Ellingsen, 2013). This technological gap in digitalizing healthcare, including sleep care, can be attributed to the challenging nature of entering the highly regulated healthcare market, as well as the difficulties associated with developing software that aligns seamlessly with healthcare practices (Fitzgerald & Russo, 2005; Ellingsen et al., 2013). This situation is disconcerting, considering that digital platforms hold great promise in addressing the increasing demands posed by factors like an aging population (Bonina et al., 2021; Islind, 2018; De Reuver et al., 2018). As the healthcare sector is struggling with the current demand and lack of resources, which will likely worsen in the future, it has become imperative to bridge this gap.

Digital health platforms that can be used by patient in their own home are key to addressing this need (Cancela et al., 2021; Golinelli et al., 2020). These digital platforms for at-home use can enable more longitudinal data collection. Larger data sets, in turn, make the application of artificial intelligence and machine learning for pattern recognition feasible and create the potential for new diagnostic insights (Arnardottir et al., 2022; Thurman et al., 2018; Cancela et al., 2021; Germine et al., 2019). Such longitudinal health-related data can consist of a wide range of data points such as lifestyle, physical activity, physiological measurements, and measuring of cognitive functioning. Due to the heterogeneity of the data collection that most multi-disciplinary research projects call for, there is a dire need for data-driven digital platforms to cope with such diverse data.

Within the healthcare sector, sleep care, in particular, holds immense potential for transformation through the power of digitization (Schmitz et al., 2022; Sveinbjarnarson et al., 2023). As one of the fundamental pillars of health, sleep affects a wide range of physiological functions. From restorative processes and hormonal regulation to cognitive performance and immune system functioning, quality sleep plays a vital role in maintaining overall well-being (Walker, 2021; Benjafield et al., 2019; Filip et al., 2017; Hillman & Lack, 2013; Karlgren et al., 2022). However, the assessment and management of sleep-related issues have traditionally relied on subjective reporting or cumbersome objective in-laboratory sleep studies, limiting accessibility, scalability, and reach (Arnardottir et al., 2021; Biedebach et al., 2023). These issues have caused a lack of longitudinal studies of sleep and cognitive function (Arnardottir et al., 2022; Tai et al., 2022; Thurman et al., 2018) and further research is needed to investigate long-term effects and fluctuations in general and sleep deficiency in particular (Arnardottir et al., 2022; Irwin et al., 2016; Deering et al., 2020).

The advent of digital platforms presents an impactful way forward to tackle this issue by revolutionizing sleep care through remote, continuous monitoring and feedback delivery to both individuals and healthcare providers (Benfeldt et al., 2020; van der Aalst et al., 2019; Pauli et al., 2021; Schrieck et al., 2023a, 2023b). Wearable devices, such as sleep-tracking sensors, can collect objective sleep data in a non-intrusive manner (Pires et al., 2023). Similarly, mobile applications can enable the longitudinal collection of subjective data. Subjective data can be understood as lived experiences, whereas objective data typically refers to sensor data. Moreover, the integration of a mix of objective and subjective data into digital platforms can help individuals can gain novel insights into their sleep quality and allow researchers to identify patterns. Thus, patients are enabled to make data-driven decisions regarding lifestyle modifications or seek medical advice (Arnardottir et al., 2021). Simultaneously, healthcare professionals can remotely monitor their patients' sleep profiles, offer personalized recommendations, and intervene proactively (Arnardottir et al., 2021; Islind et al., 2019).

Moreover, the focus of sleep care has, up until this point, been on measuring sleep with several sensors for one night or by answering surveys at a certain point in time. Due to the known variations in sleep, understanding sleep in a more holistic way is therefore needed (Biedebach et al., 2023). Ergo, tackling and grasping the longitudinal elements of fluctuating sleep patterns and cognitive function for understanding the underlying elements of sleep and tailoring personalized digital care pathways outlines the focus of this paper.

Regarding the history of sleep measurements, sleep diaries have been the primary focus of digitization efforts in sleep care (Tonetti et al., 2016; Vacaretu et al., 2019; Schmitz et al., 2022). We outline these as digitization efforts instead of digitalization efforts, as most sleep diaries have primarily been moved from

an analog survey format to a digital survey format, taking little or no advantage of dynamic structures and generativity that the design and development of novel digital solutions can bring. Taking advantage of the generative nature and integrating different users' needs have been outlined as critical factors for moving from digitization to digitalization (Kempton, 2022). Digitization is thereby understood as efforts of translating an analog artifact into a digital artifact, while digitalization is seen as efforts of fully utilizing the digital environment to enhance the practices surrounding the digital processes in a cohesive socio-technical manner.

Some efforts have been more innovative, including new interactive features such as sliders and gamification elements that allow for enhanced interaction, leading to a better user experience (Schmitz et al., 2022). Sleep diaries outline a promising way of collecting longitudinal subjective data that can aid the diagnosis of sleep disorders such as insomnia (Kristbergssdottir et al., 2023). However, the data from a sleep diary alone is, in most cases, not sufficient to identify sleep disorders with certainty (Palagini et al., 2022). While advances have been made in the development of equipment for at-home home sleep measurement devices, which can allow for sleep measurements at patients' homes (Kainulainen et al., 2021), the equipment is still costly and cannot be easily distributed to a broader demographic. In addition to that, the gold standard for at-home sleep measurements is one to three nights, which simply does not allow for enough time for fluctuations in sleep patterns, for instance, for females, where the sleep patterns can differ extensively brought on by the menstrual cycle (Óskarsdóttir et al., 2022). In sum, there have been some advances in terms of subjective data and others in terms of objective data. Still, there is a gap in the literature concerning the integration of heterogeneous longitudinal data sources into reliable care pathways, especially when it comes to cognitive functioning. Digitalizing it for at-home measuring has the potential to allow researchers to gain novel insights through the analysis of novel longitudinal data. Furthermore, due to the impact of sleep disorders on cognitive performance (Jóhannsdóttir et al., 2021; Arnardóttir et al., 2022; Guo et al., 2017; Leng et al., 2017), a digital assessment of cognitive functioning could be pivotal for collecting objective data for improved detection of untreated sleep disorders. Measuring cognition can help monitor the cognitive capacities in a person and detect symptoms of a decline, such as attention loss, the downturn of executive functions, memory impairment, or effects on mood regulation (Jóhannsdóttir et al., 2021; Guo et al., 2017; Caporale et al., 2021; Palagini et al., 2019).

Therefore, the design and development of novel digital platforms that integrate heterogeneous objective and subjective data into cohesive care pathways that enable interoperability and congruence is vital for the future of sleep care. Nevertheless, inherent challenges are involved in designing and developing such a digital platform. It is crucial to establish user engagement as a priority while simultaneously ensuring the validity of measuring cognitive functioning and other similar impactful measures. This paper presents a two-year-long action design research project aimed at designing and developing a dynamic digital platform. The unit of analysis in this paper is on the elements of the digital platform, meant for digitally measuring the cognitive functioning of our participants. Our primary focus lies in evaluating the digital platform's usability to reimagine care pathways for sleep care, specifically focusing on measuring cognitive functioning. We pose the following research question:

RQ1: What are the characteristics of the design and development of a digital platform that allow for the creation of meaningful care pathways?

Our main contribution is theorizing care pathways through digital platforms based on our novel findings from digitalizing the measurement of cognitive functioning. We provide VALID care pathways as a framework to inform the ongoing design and development process of digital platforms for reimagining care pathway delivery of the future. The framework is a conceptual tool that delineates the essential characteristics of successful and effective digital care pathways: being *viable*, *accessible*, *lean*, *informed*, and *doable* (VALID).

2 Background

There is a new dawn within healthcare, a dawn paved with digital transformation in the form of digital platforms that change care delivery. A digital platform is a piece of software that connects users with resources and services (Constantinides et al., 2018; Blaschke et al., 2019; Boudreau & Hagiú, 2009; Gawer, 2022). Thus, digital platforms provide an infrastructure to facilitate interactions, transactions, and collaborations (Smith & McKeen, 2011; Hagiú & Wright, 2015). In the healthcare context, digital platforms, often also referred to as digital health platforms, are specifically used to provide care for patients (Islind et al., 2019), and as such, digital platforms generate value for patients (Porter & Teisberg, 2006; Teisberg et

al., 2020). Previous research on digital platforms has focused on health outcomes (Faik et al., 2020; Gleiss et al., 2021), user engagement (Barrett et al., 2016; Schmidt-Kraepelin et al., 2020), user-centered design and co-design (Tempini, 2015) and on improving accessibility (Nicholson et al., 2021). Moreover, recent literature has emphasized the importance of cultivating a valuable user experience of digital platforms, which can be fostered through novel approaches such as digital nudging (Lehrer et al., 2021) or gamification elements (Schmidt-Kraepelin et al., 2020). Moreover, keeping the technical complexity of digital platforms low has been shown to improve the user experience of digital platforms (Jiang & Klein, 1999).

However, what characteristics foster a meaningful design is not entirely understood, as illustrated by the many examples of failed integration of digital health platforms in the literature (Ellingsen et al., 2013; Fitzgerald & Russo, 2005; Bygstad & Øvrelid, 2020). These studies describe designs that failed due to not meeting the needs of their users, which further capitalizes on the importance of a holistic co-design approach for digital platforms (Cancela et al., 2021; Islind et al., 2019). A careful digital platform design process involving relevant users is an important step for achieving meaningful design (Islind, 2018).

Although the research on digital platforms has rapidly grown over the past years, there are multiple parts of healthcare that digitalization has yet to dawn upon. One part that has been lagging behind in terms of digitalization efforts is the measurements of cognitive functioning, which is still dominated by laboratory settings and, oftentimes, analog processes. Let us examine that in detail. Research has shown a connection between sleep-related health issues and neurodegenerative processes (Przedborski et al., 2003). Neurodegenerative processes refer to the loss of neuron structure and function and indicators of neurodegeneration have been found in patients with obstructive sleep apnea, which, in layman's terms, is a sleep disorder where the patient's breathing is interrupted during sleep. These lead to changes in cerebrospinal fluid (Cui et al., 2022) and alterations in brain anatomy and activity as observed through structural (Chen et al., 2015; Lee et al., 2022; Koo et al., 2023) and functional neuroimaging techniques (Canessa et al., 2018; Fortin et al., 2020). Despite the growing knowledge on digital platforms, and the growing body of literature on the importance of cognitive functioning, the literature combining the two to date, is scarce.

To dive into the scarcity, we will lay out the reasoning behind why digital platforms fit well for the testing of cognitive functioning. To assess the cognitive impairments associated with sleep-related health issues in general and obstructive sleep apnea in particular, researchers have employed various neuropsychological tests in a laboratory setting, which poses a drawback as patients are in pressed environments, and the tests can merely be administered once and not continuously (Arnardottir et al., 2020). Despite some inconsistencies in findings due to methodological variations and the challenge of selecting tests with suitable difficulty levels, certain cognitive functions, such as working memory, have been consistently found to be impaired in sleep-related health issues in general and for patients with obstructive sleep apnea in particular (Bucks et al., 2017; Jóhannsdóttir et al., 2021; Saunamäki & Jehkonen, 2007; Gagnon et al., 2014). The continuous measurement of cognitive functioning is important for tracking its progression and, thus, understanding the impact of sleep on neurodegenerative processes in patients with sleep disorders. Moreover, identifying specific cognitive impairments linked to sleep-related health issues in general and obstructive sleep apnea, in particular, can direct interventions aimed at alleviating these effects, thereby enhancing the quality of life and reducing the risk of long-term neurological decline.

Until now, cognitive functioning assessments have thereby predominantly taken place within controlled laboratory environments. However, the concept of continuously monitoring cognitive functioning over time presents a groundbreaking opportunity to deepen our understanding of how cognitive performance correlates with sleep patterns. Traditional in-lab testing can be burdensome and exhausting for participants, as it usually involves a succession of tests with little respite. Furthermore, in-lab testing requires intense manual labor. Previous research has largely concentrated on the creation and adaptation of singular cognitive tests for specific devices by digitizing them, moving them from analog to digital without altering any conditions around them. Instead of merely making them available for at-home measuring, there is a dire need to embrace the full extent of the novel digital means that are at the forefront (Arnardottir et al., 2022b). Therefore, it is vital to research efficient and modern approaches to collect and visualize cognitive data over an extended period of time in order to tailor digital care pathways

and provide an in-depth understanding of the impact of sleep. This would provide a more accurate representation of individuals' cognitive abilities (Jaeger, 2018). Against that backdrop, our study proposes the digitalization of multiple cognitive tasks, integrating them into a single digital platform. This approach not only facilitates a more streamlined and efficient monitoring process but also offers a comprehensive overview of cognitive function trends over time.

To address these challenges, Jóhannsdóttir et al. propose a set of cognitive tasks suitable for assessing various cognitive functions specifically in the context of sleep health. To cover different domains of cognitive functioning, Jóhannsdóttir et al. recommend, among others, the following measures: (i) simple reaction time, (ii) word list learning, (iii) digit symbol coding, (iv) line orientation and (v) paced auditory serial addition test. Furthermore, Ballesio et al. highlight (vi) the Tower of London as a suitable task for measuring cognitive functioning in sleep research, as individuals with insomnia tend to exhibit worse performance on this task compared to individuals without insomnia (Ballesio et al., 2019).

Firstly, the simple reaction time task measures motor skills by timing an individual's reaction time to a stimulus (Deary et al., 2011). Participants are asked to react to a visual stimulus by pressing the screen or a key on a keyboard. *Secondly*, the word list learning task measures the immediate and delayed recall of 10-15 words (Lezak et al., 2004). Participants are presented with a series of semantically unrelated words in either written or audio form and are then asked to recall as many as possible (de Sousa Magalhães et al., 2012). *Thirdly*, the digit symbol coding task is designed to evaluate attention and processing speed of information (Wechsler, 1955). Participants are presented with a table that maps the numbers 1-9 with specific symbols. Participants are then presented with a series of symbols and need to enter the number corresponding to each symbol as quickly as possible in a given time period (Jaeger, 2018). *Fourth*, the line orientation task measures visuoperceptual abilities, visual matching, and spatial relations (Lezak et al., 2004). Participants are shown a single line at a specific angle, followed by a set of 15 lines with different angles. Their task is to match the single line with the line in the set that has the same angle in a specified time interval (Strauss et al., 2006). *Fifth*, the paced auditory serial addition test (PASAT) assesses working memory, divided attention, information processing speed, and sustained attention (Lezak et al., 2004). Participants are either read or shown a random series of numbers from 1-9 and are required to add each pair of numbers. In the digital version, a circle of numbers from 1-18 is displayed on the screen. Participants are tasked with listening to or reading the first two numbers, calculating their sum, and clicking on the corresponding answer on the number circle as quickly as possible. The process continues for each subsequent number. This measure is frequently used for studying sleep disorders (Fulda & Schulz, 2001). *Sixth*, recommended by Ballesio et al. (2019), is the Tower of London task. The Tower of London task evaluates executive functions such as cognitive flexibility and updating (Baker et al., 1996). Participants are shown three posts of different lengths and three colored balls. By rearranging the balls one at a time, participants need to transform the starting pattern of the balls on the posts into the given goal pattern.

The digitalization of measuring cognitive functioning is scarce, and the practices surrounding it, to date, are analog and rigid. Furthermore, measuring cognitive functioning calls for reliable data and data traceability, both elements for which digital platforms work well. The literature on digital platforms for healthcare purposes and ways to design those is also lagging behind, creating a space that this paper contributes well into. Moreover, recent years have brought new interest into the field of IS; the focus on human flourishing. Human flourishing refers to the way the design of information systems can support a good flow within the continuum of physical, emotional, social, and psychological dimensions, all at the same time (Hylving et al., 2024). Our paper thereby also contributes to that ongoing discursive commitment by focusing on the design of a digital platform to measure cognitive functioning, ultimately supporting human flourishing and better insights into the notion of the self.

3 Methodology

In a two-year spanning research project, we designed and developed a large-scaled digital platform. The platform includes various components for sleep research and at-home measuring of cognitive functioning, which is the focus of this paper. Figure 1 illustrates the design and development process following an Action Design Research (ADR) approach to measuring cognitive functioning. ADR is a methodology that combines action research and design science to address complex issues by iteratively designing and

testing artifacts in real-world environments (Sein et al., 2011). This approach emphasizes joint development by researchers, experts, and users. ADR does not only help to develop effective practical solutions but also to uncover knowledge through the learnings from designing the solution (Mullarkey & Hevner, 2019).

In a co-design approach, we involved multiple stakeholders in the design process (Islind, 2022). More specifically, we have utilized co-design workshops with neuropsychologists to ensure measurement validity while aiming for high usability and user experience alongside end-user involvement with a total of 55 participants. The user tests employed a comprehensive approach to evaluate the usability of the digital platform. In the alpha phase, moderated user tests were performed individually under supervision with a focus on user experience. In contrast, the participants of the self-moderated user tests in the beta phase only received initial instructions and an opportunity for follow-up questions once and completed the tasks otherwise without supervision. Firstly, participants were asked to complete various cognitive tasks on the platform, which allowed us to gather real-time observational data on their interactions and behaviors during supervised sessions. Following the completion of these tasks, participants were asked to complete questionnaires to further assess their experiences and provide additional feedback.

The questionnaires that we used to evaluate were the System Usability Scale (SUS) and the AttrakDiff. The SUS, developed by Brooke in 1996, is widely validated. The questionnaire measures usability and is comprised of ten rating scales ranging from 0 to 10, and the ratings are added up to an overall usability score that ranges from 0 to 100 (Brooke, 1996). The average SUS score, generally, is 68, and any result below this threshold indicates some underlying issues. If the score exceeds 80.3, the system is considered to be of high quality.

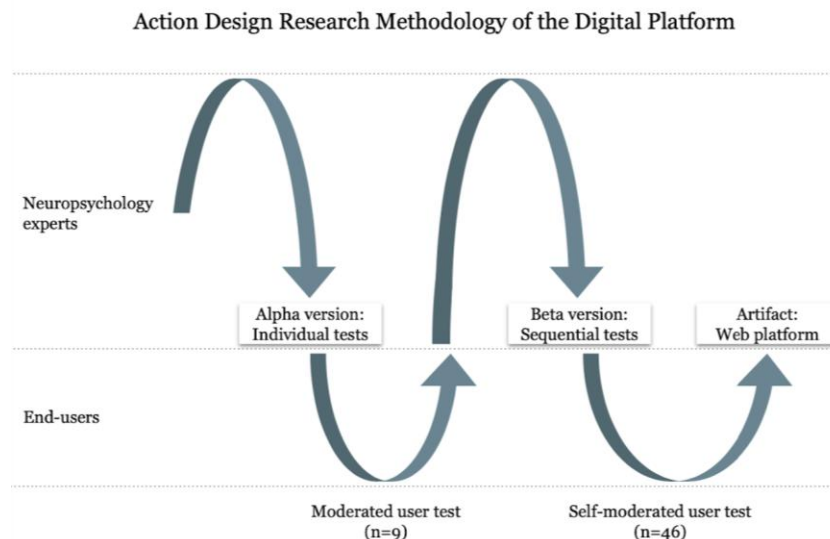


Figure 1. Our Design and Development Process Following the Action Design Research Methodology

The second questionnaire we used was the AttrakDiff. The AttrakDiff measures experienced hedonic and pragmatic quality and user experience of interactive products (Hassenzahl et al., 2003). It evaluates four aspects of the artifact, those being pragmatic qualities (PQ), hedonic qualities—identity (HQ-I), hedonic qualities—stimulation (HQ-S), and attractiveness (ATT). PQ describes the usability of the platform and how well users are achieving their goals. HQ-I indicates how well the users identified with the product. HQ-S measures to what extent a product supports the need to develop and move forward. ATT describes the global value of the artifact based on the quality of perception.

In order to measure cognitive functioning such as the aforementioned ones, researchers predominantly utilize software tools for measurement in experimental settings. These software tools are specifically designed to create and execute psychology and neuroscience experiments within an in-laboratory setting. The features of these software tools include different capabilities of stimulus presentation, response

recording, and data analysis. However, they are not commonly optimized for extensive customization, wide browser and device support, or the data integration necessary for suitable testing of cognitive functioning at home.

We designed and developed the digital platform as part of the Sleep Revolution. The digital platform design followed the overall design approach of co-design alongside the graphical profile of the Sleep Revolution project while keeping a neutral and functional look to allow for high validity of the cognitive measuring. The measures were implemented according to the literature, but several elements on the broad spectrum of gamification were prioritized by our users and were implemented to enhance the user experience. After careful consideration, we chose not to use any of these available software tools on the market and instead designed and developed a custom digital platform for our pan-European project as we needed a cohesive approach to cognitive testing. Furthermore, we wanted the data to be readily available for everyone involved in the project, ergo 39 hospitals, universities and clinical practices in multiple countries with over a thousand participants using the digital platform for clinical studies across Europe. An additional element that further strengthened the decision was that we needed the digital platform and its cognitive tasks to be available in 17 languages, which none of the existing software tools supported.

These are further elaborated on in the results section. In the project, measuring cognitive functions has been conducted in a laboratory setting. However, this is cost- and labor-intensive and does not allow for effective scaling between countries, which makes it unfit for broader distribution. To overcome these drawbacks, we chose to design and develop a custom module for at-home cognitive testing as part of our digital platform, primarily to ensure it could integrate seamlessly with our existing database and other services. This approach has allowed us to create specific functionalities that meet our unique research requirements. We found that such capabilities were not readily available in established platforms for cognitive testing. Additionally, having complete control over updates and maintenance meant that we could make adjustments as needed, which was essential for maintaining stability and reliability that matched our specific workflow needs. Moreover, implementing the cognitive functioning software ourselves was particularly advantageous for supporting at-home testing. The flexibility of our digital platform has been indispensable, especially as one of the goals of the Sleep Revolution is to move all measurements from the hospital and the laboratory setting to the patient's home. By designing and developing our own digital platform to adapt to various home environments, we have been better able to manage experimental conditions and data collection, ensuring consistent quality and integrity of data across diverse settings and in addition to that, it has an impact on the data governance, as well-structured data governance is one of the pillars of the project.

The digital platform underwent testing in two phases to ensure its usability and user experience. In the alpha phase, we organized a workshop involving two experts in neuropsychology. The primary goal of this workshop was to gather essential requirements for developing a platform that enables individuals to complete cognitive tasks in their own homes and to decide on a minimal but sufficient set of cognitive tasks to include on the platform. The tasks that were selected due to the results of previous studies and implemented as part of the platform were: (i) simple reaction time, (ii) word list learning, (iii) digit symbol coding (see Figure 2c), (iv) line orientation, (v) paced auditory serial addition test (PASAT) and (vi) Tower of London (see Figure 2b), all available via an overview (see Figure 2a). For the word list learning task and the PASAT, written and verbal versions were provided. In the written version, text was displayed on the screen. In contrast, the verbal version involved the presentation of the text as audio, without any visible text. Counting those as alternative versions of different measures, the platform included eight measures in total. We used the requirements gathered from the workshop to create the elements within our digital platform that incorporated the recommended measures discussed in the related work section.

3.1 Data Collection and Data Analysis

In the alpha phase, we conducted co-design workshops with two neuropsychology experts to design and develop the digital platform. The first version of the functionality of measuring cognitive functioning in the digital platform was then assessed by conducting a moderated experiment involving nine participants with a focus on user experience. The participants were asked to complete the cognitive tasks and to express their opinions on the digital platform while they performed the tasks. After the completion of the tasks, the participants were asked structured questions about their thoughts on the digital platform and their understanding of the cognitive task instructions. Finally, the participants were instructed to fill out the AttrakDiff and SUS questionnaires. Each participant took part in this experiment individually and was closely observed by an experimenter for the entire duration, who also noted any difficulties the participant

experienced in using the digital platform. Since the completion of the task was supervised by an experimenter, we refer to this experiment as ‘moderated’.

During the beta phase, we continued to refine the digital platform in an iterative manner based on the feedback received from the alpha phase. To ensure the usability changes were aligned with user preferences and needs, we conducted more workshops with the same two experts in neuropsychology. During these workshops, we discussed the results of the user tests conducted in the alpha phase and identified specific areas for improvement. To further evaluate the digital platform's performance and gather more comprehensive data, we conducted a comprehensive experiment with 46 participants. We presented the project to the participants and provided an explanation of the cognitive tasks they would be required to perform in the user test. Each participant completed the set of cognitive tasks four times as part of our experiment. The first administration of the tasks took place during a classroom session in the sleep course, where participants were able to gain support and clarify any uncertainties about the digital platform and the experiment setup. Subsequently, the participants completed the tasks three more times at 1 p.m. self-moderated without supervision. The testing sessions were conducted under three different conditions: after a 4-hour sleep restriction, after a normal night of sleep, and after a night of sleep extension. Importantly, there was always a night of normal sleep between each testing condition to ensure sufficient recovery and eliminate potential carry-over effects.

Table 1 provides an overview of the number of participants involved in each round of the cognitive measuring, as well as the number of participants who successfully completed each of the five cognitive tasks in each round on the digital platform.

Table 1. Number of Participants Who Completed the Cognitive Tasks in the Two Testing Phases

Cognitive Task	Alpha Phase	Beta Phase			
		Baseline	Restricted Sleep	Normal Sleep	Extended Sleep
Auditory verbal learning	9	46	43	41	31
Digit symbol coding	9	45	43	41	30
Line orientation	9	45	43	41	31
PASAT-C	9	42	40	41	30
Tower of London	9	45	43	41	30

Following the completion of the tasks, we asked the participants to provide feedback through the SUS and AttrakDiff questionnaires. Additionally, a structured written form that included open-ended questions was sent to the participants, which they could answer freely. The form covered various aspects of the digital platform, including inquiries about the participants themselves and their experiences with the digital platform. This feedback provided an opportunity for the participants to share their thoughts on the digital platform's functionalities, ease of use, and overall satisfaction. We then performed a qualitative analysis of the feedback, labeling any negative and positive aspects of the digital platform that the participants reported, and subsequently grouped them by themes.

4 Results

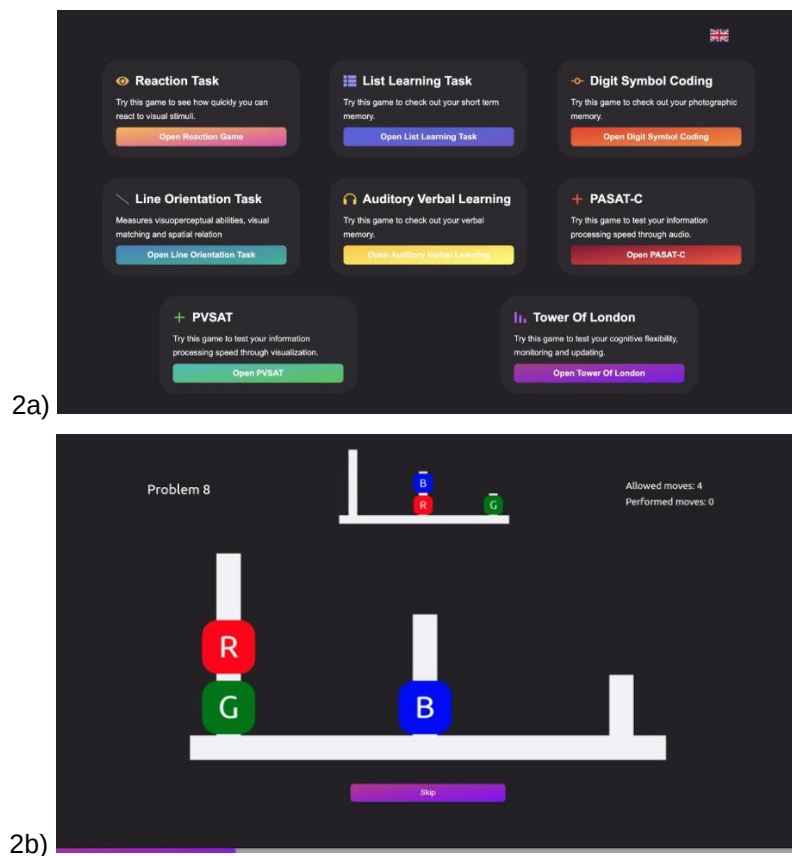
As stated earlier in this paper, the digital platform as a whole is large-scale, but the particular part analyzed for the purpose of this paper is the measuring of cognitive functioning. The digital platform takes in and integrates objective and subjective data from a mobile application that includes a sleep diary while also taking in data from wearable devices, such as a smartwatch. Specifically, sleep studies that have been conducted in the context of the Sleep Revolution project and have used the digital platform have been collecting data from various sources. These studies have gathered sleep-related data from the Sleep Revolution mobile app, Withings scanwatch, at-home self-applied polysomnography, and additional measurements like body weight and height. All data sources, including the results from cognitive tasks, are sent to and stored in a secure database that is part of the Sleep Revolution platform. Researchers gain access to these results and perform data analysis and machine learning to uncover patterns and gain new insights into sleep health.

The overall goal of the digital platform, as such, is to enhance and modernize sleep care. The cognitive tasks had, up until this point, been delivered in a laboratory setting. However, the challenge of delivering

them through a digital platform into the participants' homes in order to effectively monitor fluctuations in cognitive function alongside a decline in connection with sleep or lack of sleep is an important step both in terms of reimagining care pathways and moving diagnostics and treatment from the hospital to the home. The alpha phase of our research essentially outlined the development of the cognitive tasks in the digital platform, whereas the beta phase included digitalization, where we embraced the full extent of the digital technology by adding gamification elements such as a progress bar. During the beta phase, we gathered usability data through SUS and user experience data through AttrakDiff alongside qualitative results from the written form as well as the result data from the cognitive tasks on the digital platform.

4.1 Digital Platform Design

The digital platform was designed and developed following the requirements gathered in the workshop with neuropsychologists. The design of the digital platform was created prioritizing usability while maintaining validity of the measuring tools. A set of cognitive measurement tools were selected carefully to offer a minimal set of tasks that cover a wide variety of cognitive domains. Progress bars were implemented for tasks where they did not affect measuring validity. We implemented an overview of all available tasks for participants to start the tasks themselves, as well as a view that would present a predefined set of tasks sequentially. The page with the overview of the tasks and selected other task views is shown in Figure 2.



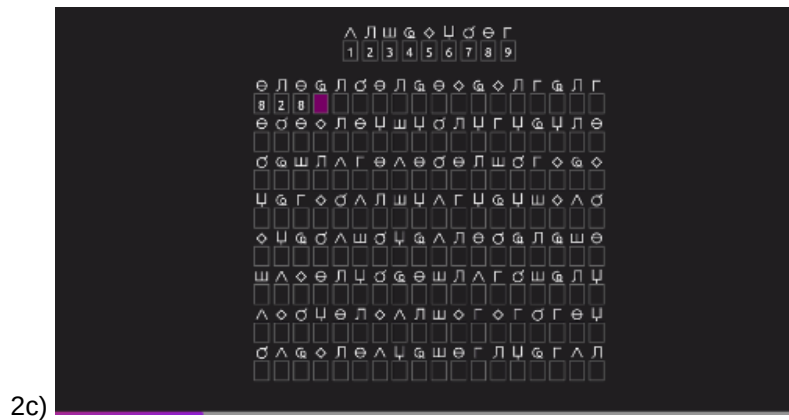
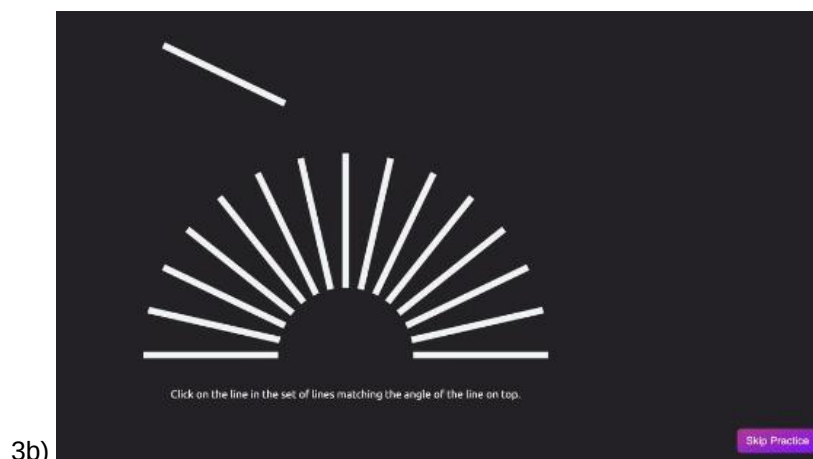
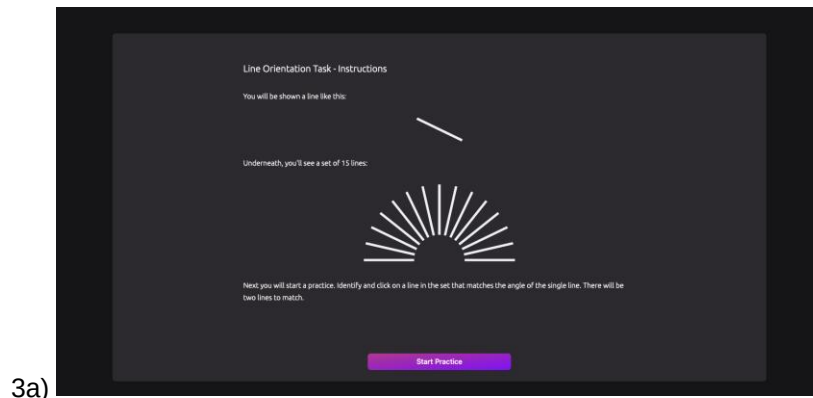


Figure 2. Overview of the available cognitive tasks in the digital platform. Users can select specific tasks from that overview to perform (see 2a). Selected views of the Tower of London (see 2b) and Digit Symbol Coding task (see 2c).

Each task started with a display of the task instructions (see Figure 3a) and an optional practice round (see Figures 3b, 3c, and 3d). The practice round included simple instructions and feedback. Users can solve the practice round without time constraints and can repeat the practice round until they solve it correctly. After the practice round, the users receive additional information that the round is about to start, and they can initiate the task with a button click. Upon completing the task, the users receive an overview of their task performance and can finish and return to the overview or the next task. Figure 3 shows these steps in the example of the Line Orientation task.



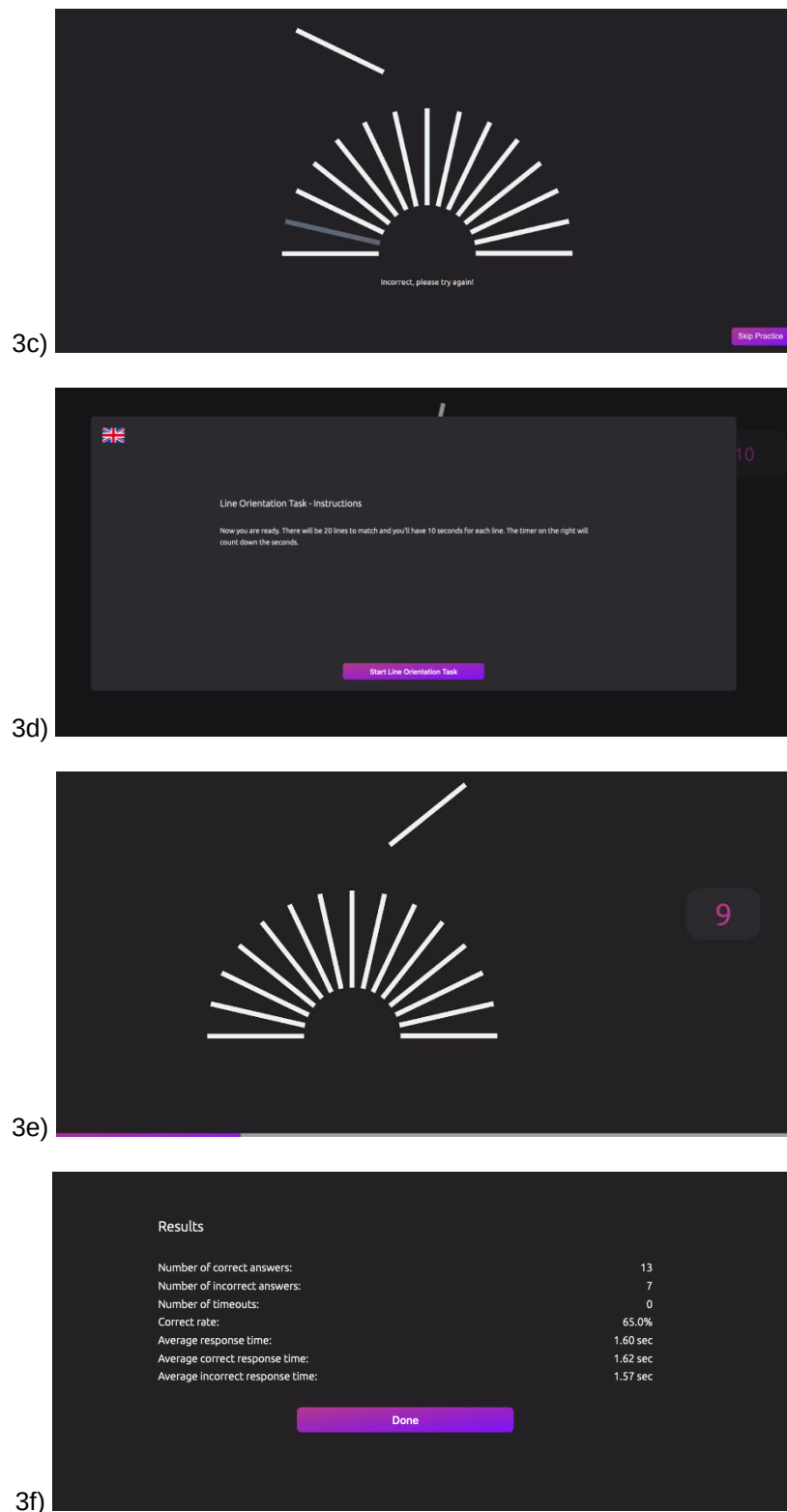


Figure 3. The different views and steps involved in performing a cognitive task in the digital platform, are shown in the example of the Line Orientation task. The steps completing the task are in order: (3a) users receive instructions for the task, (3b, 3c, and 3d) the users start a practice round with short instructions and feedback and without time constraints to ensure they understand (users can also skip practice in case they are already familiar with the tasks), (3e) the users perform the cognitive task, and (3f) the users receive a summary of their task performance and can return to the overview page.

4.2 Usability of the Digital Platform

The digital platform's final SUS score from the moderated user testing was 88.89, which indicates that participants considered the usability of the digital platform very good.

The digital platform's final SUS score from the self-moderated observation study was 66.32, indicating that participants considered the usability of the digital platform to have some underlying issues. The results from the form questions indicate that those issues were related to confusion regarding the task instructions. While optional practice rounds and detailed instructions were provided for all tasks, participants did not fully understand all tasks, which led to frustration.

4.3 User Experience of the Digital Platform

Figures 4, 5, and 6 depict the AttrakDiff results from the moderated user testing. The portfolio presentation in Figure 4 averages values of the dimensions PQ and HQ. The horizontal axis shows the PQ and the vertical axis shows the HQ. As shown in Figure 4, the confidence is slightly higher on the HQ scale, which means that participants were more conflicted on HQ than on the PQ. According to these results, the participant's experience of the digital platform was as desired, and they felt like they were completing tasks and moving toward a goal.

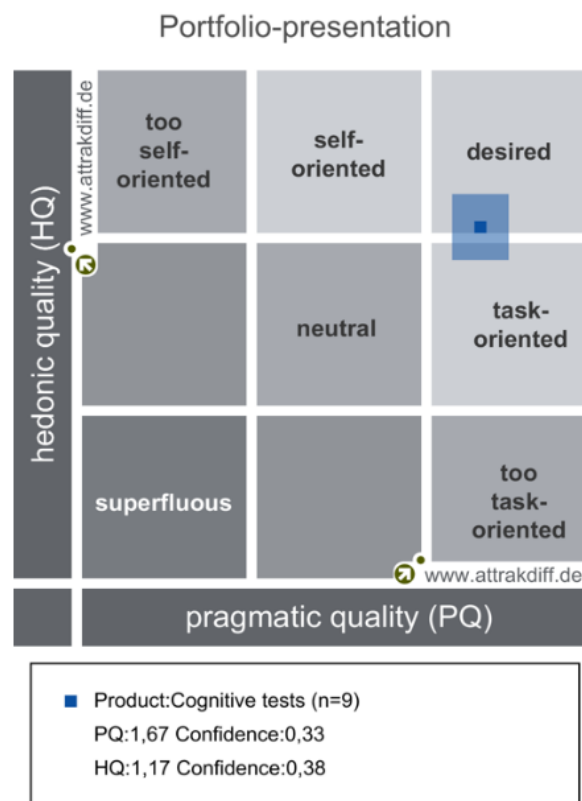


Figure 4. Moderated User Testing - AttrakDiff Portfolio Presentation

The diagram of average values in Figure 5 shows the score of the four categories in AttrakDiff and the overall attractiveness rating. PQ received a high score of 1.67 indicating that the users were successful in solving the task. HQ-I received a high score of 1.48, meaning the users can identify well with the digital platform. HQ-S received a score of 0.86. This is the lowest score, meaning the users felt the least support in the need for personal development. ATT received a high score of 2.44, indicating the users found the digital platform attractive.

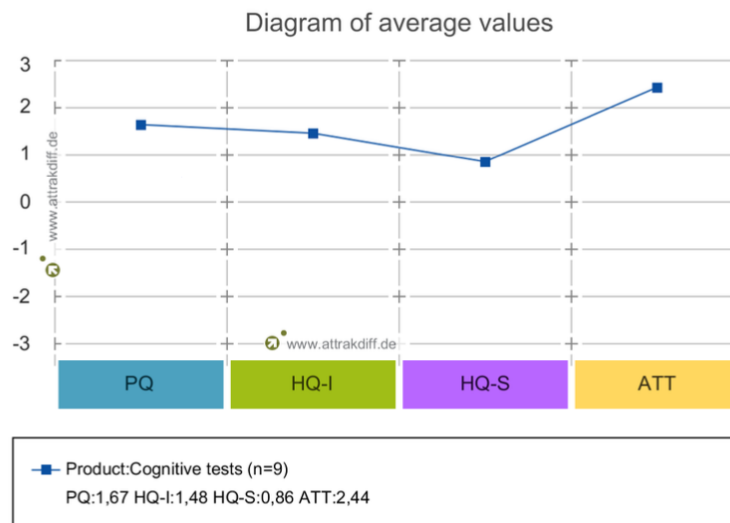


Figure 5. Moderated User Testing - AttrakDiff Diagram of Average Values

The description of the word pairs in Figure 6 shows the mean values of word pairs. It is noticeable that the attractiveness scores were high. Only one-word pair (conventional) went below the neutral threshold, while two other pairs (cautious and ordinary) were close to the threshold.

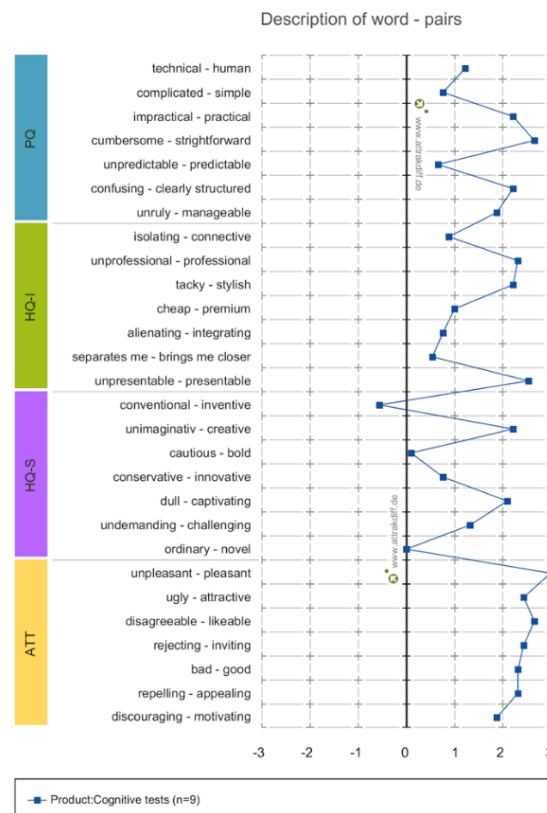


Figure 6. Moderated User Testing - AttrakDiff Description of Word Pairs

Figures 7, 8, and 9 depict the AttrakDiff results from the self-moderated observation study from 36 out of 46 participants who answered the questionnaire. The portfolio presentation in Figure 7 shows that the confidence is higher on the PQ scale, which means that participants were more conflicted on the PQ

answers compared to the HQ answers. According to these results, the participant's experience of the digital platform was neutral.

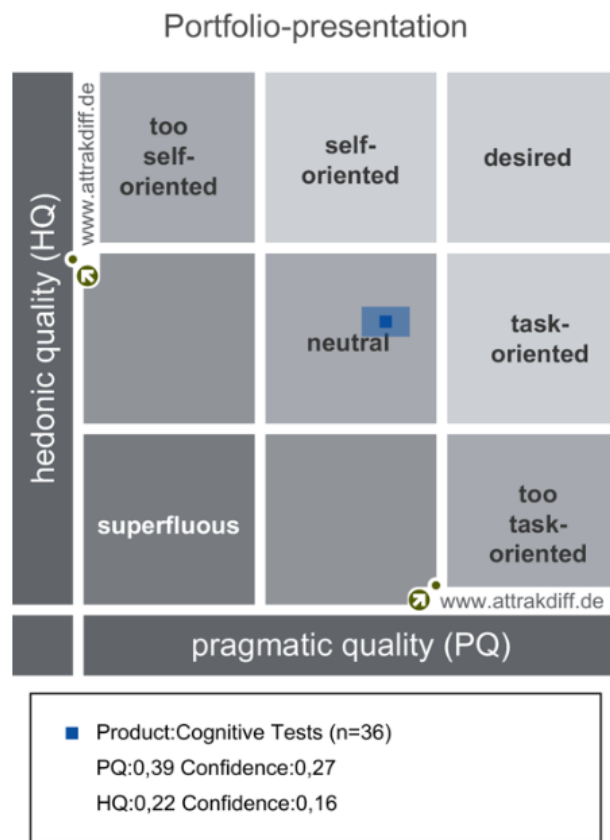


Figure 7. Self-Moderated Observation Study - AttrakDiff Portfolio Presentation

Figure 8 shows the diagram of average values received from the AttrakDiff questionnaire. PQ received a score of 0.39, HQ-I received a score of 0.17, HQ-S received a score of 0.26, and ATT received a score of 0.21. Neither of these results stands out strongly. PQ is the highest value and suggests that the users perceived the digital platform as functional and usable. HQ-I and HQ-S were lower, indicating that the digital platform does not strongly contribute to user identity or provide much stimulation to the users. ATT was also modest, reflecting a generally neutral overall impression.

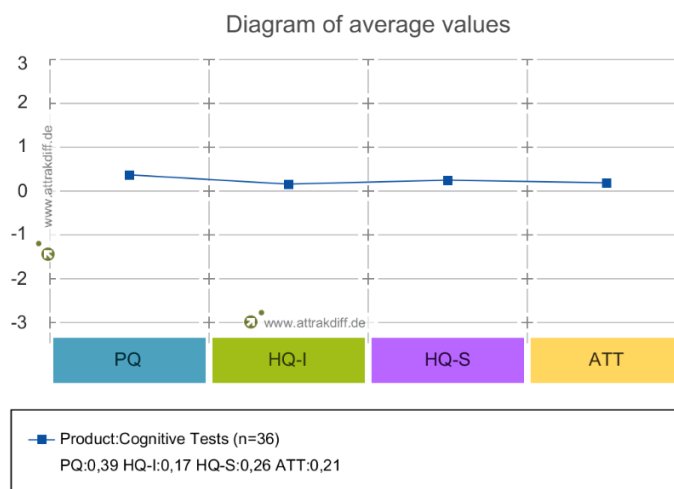


Figure 8. Self-Moderated Observation Study - AttrakDiff Diagram of Average Values

The description of word pairs in Figure 9 shows that most values are around the neutral threshold. It is noticeable that users found the digital platform professional and challenging, but also that it was isolating. In the context of an AttrakDiff evaluation, isolation refers to how separated or detached the user feels when interacting with a digital product.

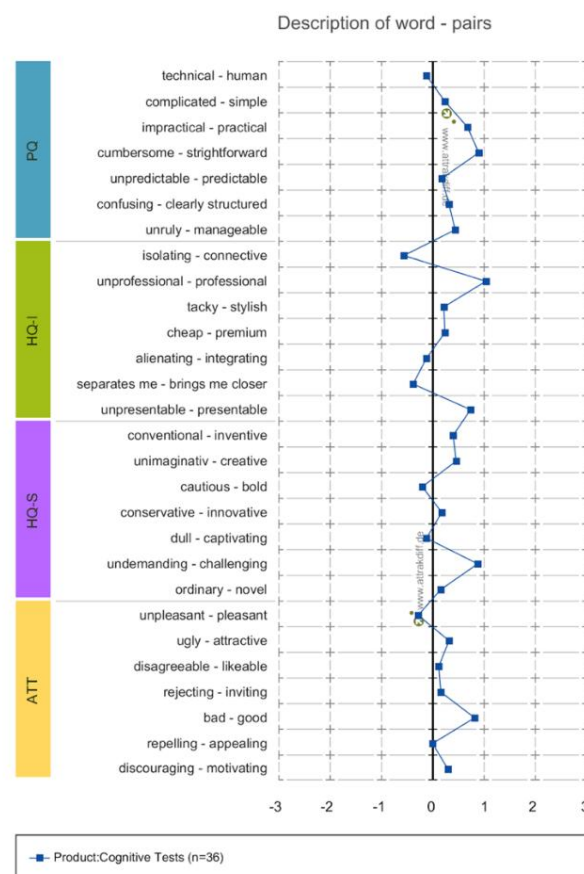


Figure 9. Self-Moderated Observation Study - AttrakDiff Description of Word Pairs

The results of the study show that the majority of the participants liked the overall look and feel of the digital platform and thought it was easy to use and understand. Moreover, they also reveal that the instructions for PASAT-C were not clear enough and it was hard for participants to understand what they were supposed to do even though they were offered a practice phase.

The SUS scores showed a notable difference between the two test phases. The score from the participants in the moderated testing was 88.89, while the score from the 36 participants from the self-moderated test was 66.32. A reason for this difference in the average SUS score among participant groups could be attributed to the distinct setups for each group. In the moderated tests, the focus was on the look and usability of the digital platform and the participants were able to take breaks between the tasks. They also received the questionnaires by mail and could thus fill them out at a time that was convenient for them. In contrast, participants in self-moderated tests had to take the set of cognitive tasks for the fourth time in a span of six days right before answering the questionnaires. In particular, the task they completed last, which was the PASAT, is designed to create and evaluate frustration in participants. This might have influenced the perceived attractiveness and usability of the digital platform negatively. Taking these circumstances into consideration, it can be concluded that the usability of the digital platform is good even though the SUS score from the self-moderated observation study test group was slightly below average.

In addition, we found a difference in the AttrakDiff results between the two test groups. All four scores were lower in the self-moderated test group than in the moderated test group, displaying a similar trend as the SUS results. The biggest difference was in attractiveness where the score from the self-moderated test group was 0.21 but the score from the moderated test group was 2.44. The reason for this could be

that the sequential task setup is not as attractive as the individual task setup. In the individual task setup, participants started on a landing page where they could select the tasks and participant feedback from the moderated testing indicated that this was the most attractive view of the digital platform. In the sequential task setup, this view was missing. The attractiveness of the sequential task setup might be improved by making the results screens, which are not part of the tasks themselves, more attractive.

5 Discussion

Despite the high potential for impactful care pathways through digital health platforms, there are still open questions in terms of what digital care pathways could look like (Connell et al., 2019) and which pitfalls to avoid (Ellingsen et al., 2013; Fitzgerald & Russo 2005; Bygstad & Øvreliid, 2020). Patient-centered design that provides a good user experience has been shown to be important for the meaningful design of a digital health platform. A good user experience is fostered through a platform that is readily accessible, easy to understand, and of low technical complexity (Jiang & Klein, 1999).

The insights we gathered throughout the action design research process further shed light on the unique challenges in the design of digital care pathways. Our workshops with experts revealed that aiming for high usability in a digital platform for measuring cognitive functioning while maintaining the reliability of the measurements is a delicate balancing act. This finding is in line with the common reason for failed health applications: low usability (Ellingsen et al., 2013; Fitzgerald & Russo, 2005; Bygstad & Øvreliid, 2020). When the digitization of healthcare tools focuses the main attention on achieving validity, usability and user experience can unintentionally be neglected. However, the most reliable and effective tool is arguably of little use when it achieves only low rates of user engagement and compliance. We can, therefore, attribute the lag of digital health platforms (Ellingsen & Monteiro, 2012; Monteiro et al., 2013; Fitzgerald & Russo, 2005; Fitzpatrick & Ellingsen, 2013) to two main factors. Firstly, user experience and usability have proven low, which in turn leads to low acceptance of digital health applications. Secondly, the provider perspective has been valued higher in comparison to user perspectives, which in turn leads to a mismatch between technology and needs (Teisberg et al., 2020).

It is therefore of the utmost importance to employ a co-design approach for digital care pathways (Islind, 2022; Cancela et al., 2021; Islind et al., 2019). Finding the delicate balance of designing a reliable but engaging tool is a complex but worthwhile endeavor and can best be achieved by involving members from both the user and expert group in multiple stages of the design process. In our case, the workshops with experts and the usability and user experience tests with end-users resulted in several specific learnings that influenced our digital platform design:

Use a web platform to maximize accessibility. For the tasks to work for participants regardless of the operating system they are using, a web platform is a preferred format to deliver the tasks. Accessibility is an important factor for the success of digital health platforms, and it is therefore imperative to support as many devices as possible. In addition, digital platforms that run in the browser do not require an installation step, which contributes further to achieving a low technical complexity (Jiang & Klein, 1999). All participants in our user tests were able to run the cognitive tasks on their own personal computers. Aside from supporting multiple operating systems, browser compatibility should be prioritized in the development. Digital platform performances can vary by browser, and it is imperative to ensure a comparable performance.

Display progress between task rounds. Progress bars are a vital element of UX design. They grant the user a sense of control and help to keep them engaged (Harrison et al., 2010). Our results showed that the attractiveness and usability suffered in a sequential task setup. If such a sequential task setup is required for proper measuring of cognitive functioning, a progress bar between tasks has the potential to uphold the users' engagement.

Avoid using a sequential task setup if possible. The attractiveness of the system suffered from the delivery of the tasks in a continuous sequential format. While conventional cognitive measuring in a university or clinical location often involves a sequential task setup due to temporal and location constraints, participants can be given the flexibility to complete one task at a time in an at-home setting. It is important to leverage the advantages of the environment to improve the UX design.

Design engaging interfaces around the task views. Digital cognitive tasks have been carefully designed and even small deviations from validated designs can potentially render the measured data unreliable. Therefore, the task views have to be designed following official guidelines for the

implementation and cannot be updated with engaging design elements without validation. The results of our user experiments showed that participants who were only exposed to the task views in a sequential setup rated the attractiveness of the digital platform lower than the users who completed the tasks individually and were brought back to a more attractive overview screen of the tasks. It is therefore important to use engaging and attractive designs of views around the task views, such as the landing page, instruction page, or results page which are not subject to those restrictions. As our results showed, participants perception of the digital platform was better when presented with the more attractive overview screen.

Minimize distractions in the digital environment. Even in an in-laboratory setting, the involved experts in neuropsychology reported interruptions of the measuring through phone calls and notifications participants received. While this can also not be fully controlled in an at-home setting, since participants complete the tasks on their own devices, certain technical options are given to minimize those distractions. We used a full-screen mode to deliver the tasks, and further options can be explored in terms of notification oppression and warnings if the browser tab is not in focus.

Collect metadata for post-collection data validation. While the prevention of unreliable data is a priority, it is equally important to enable post-validation methods (Ercole et al., 2020). Moreover, in-laboratory measuring of cognitive functioning is commonly done with special equipment, such as keyboards and mice, that shows minimal delays. At home, participants might not have comparable equipment. It is, therefore, vital to collect metadata such as timestamps and device or browser information to include in the analysis. Metadata can also potentially be used to identify whether the participants were focused on outside distractions, thus enabling further validation and rating of the data reliability.

Incorporate guided practice rounds. Participants showed difficulties understanding the tasks just through instructions. Considering the emphasis on usability, user experience, and the importance of fulfilling participants' needs (Teisberg et al., 2020; Barrett et al., 2016; Schmidt-Kraepelin et al., 2020; Tempini, 2015) while designing and developing digital health platforms, navigating possible solutions for this issue is a priority. In light of that, the practice phase can, for instance, be improved through a mandatory trial round with insightful feedback. This is especially important in an unsupervised setting. A practice round can not only help users understand their tasks but also ensure that the technical equipment is fully working, e.g., the audio is audible for the user. Practice rounds should be as short as possible to avoid frustration before the task as well as learning effects. At the same time, they should be sufficiently long for users to understand the nature of the task. Insightful feedback on errors in the practice round can enhance the user experience additionally and is to be preferred over purely positive and negative feedback.

5.1 VALID Framework: Characteristics of Digital Care Pathways

While the presented learnings from this study are specific to our case for at-home cognitive measuring in a digital platform, we argue that the underlying motivations, challenges, and contributions are not. We find that our learnings provide valuable insights into generally desirable characteristics of digital care pathways. These elements were conceptualized and synthesized into the VALID framework, which we propose as a contribution to the field of digital health platforms. The framework encapsulates a set of empirically derived design guidelines that inform the creation of effective digital health platforms. This conceptual framework extends beyond our immediate study, offering valuable insights into the general design and development practices of digital health solutions. In Table 2, we show which characteristics we derived from our results and learnings from the action design research to inform the creation of the VALID framework.

Table 2. Elements of VALID Framework in our Digital Platform for At-Home Measuring of Cognitive Functioning.

Characteristic	Examples in the digital platform design
Viable	The cognitive tasks were designed following official guidelines and were evaluated by experts. Gamification elements to improve user experience, such as progress bars, were only added when previous research showed that they had no influence on measurement outcomes. A full-screen mode was used to deliver the task and make it less

	likely for users to exit the digital platform during cognitive measuring and minimize distractions that could compromise measured results.
Accessible	The digital platform was designed to be accessible through the most popular browsers on desktop computers. Instructions and practice rounds were offered to make it easy for all users to understand and complete the tasks on the digital platform.
Lean	Selected gamification elements with a clear purpose, such as progress bars, were added to improve user engagement and minimize frustration while keeping the interface designs straightforward. A user-friendly overview page of the cognitive tasks was created in a simple yet friendly design to act as a clear and attractive landing page.
Informed	Metadata was collected in the form of timestamps to be able to perform an informed analysis of the measurement validity in the future.
Doable	An option was offered to complete each task individually to allow for more flexible time management instead of following the traditional sequential task setup in laboratory settings.

To develop the VALID framework, we began with a systematic analysis of the learnings we drew from our co-design, user evaluations, and usability tests conducted to evaluate the usefulness, suitability, and proficiency of our digital platform for at-home measuring of cognitive functioning. Initially, the learnings were categorized into themes reflecting recurrent challenges and successful interventions. These themes informed the identification of key characteristics that should be taken into consideration in the design and development of a digital health platform in general. These characteristics were then mapped to specific examples and interventions within our digital platform, forming the basis of the VALID framework as presented in Table 2.

Each characteristic of the framework — Viable, Accessible, Lean, Informed, and Doable — combines insights derived from our findings. For example, the 'Viable' characteristic is based on the importance of following the expert requirements for the design in order to not compromise test validity by only embedding gamification elements such as progress bars when it did not affect the measurements. 'Accessible' was informed by user feedback, emphasizing the need for clear instructions and showing the benefits of practice rounds with detailed feedback. The 'Lean' characteristic was drawn from feedback that emphasized the importance of a clear design with few but purposeful design elements. The 'Informed' characteristic was derived from the need to collect metadata for validation that experts expressed in order to obtain reliable, high-quality data. Finally, the 'Doable' characteristic came from the feedback and observations that the sequential presentation of tasks typically done in laboratory settings was difficult for participants to complete.

We encapsulate the characteristics into the VALID framework for meaningful digital care pathways that foster a design that is:

- **Viable:** Digital health interventions need to be, above all, 'viable' in their implementation. This means that a system is in accordance with scientific findings and that it is able to generate intended value through health outcomes. Scientific soundness needs to be shown through rigorous user testing and evaluations. A co-design process that includes experts at every stage of the development phase is vital to ensure that the system is not only accepted by the end-users but also that it generates value for them and is scientifically sound. Therefore, perspectives of patients, healthcare professionals, and researchers should be included in the design.
- **Accessible:** Digital care pathways must prioritize accessibility to reach a broader audience, both technologically and functionally. The functional design of digital care pathways should be straightforward and user-centered. Cluttered interfaces and vague instructions can lead to user frustration and cause the user to feel a loss of control. Such negative experiences can significantly diminish the user experience and the system acceptance. From a technological standpoint, supporting a variety of devices is vital to ensure inclusivity. Thus, web applications are particularly suited as they can be delivered through different browsers on various devices.

Furthermore, web platforms eliminate the need for installation, further reducing technical complexity (Jiang & Klein, 1999). Similarly, restricting the digital application to a specific laboratory setup significantly narrows down the potential audience. Only when users can engage with the application on their own devices, on their own schedule, and in the comfort of their homes can we reach the full potential of accessible care pathways.

- **Lean:** A lean design of the digital platform that hosts the care pathway is a key component of building an engaging, doable, and accessible system. A 'lean' design describes the use of straightforward, clean, and efficient interfaces. Including elements such as nudging or gamification can help to make the digital platform more engaging but at the same time, it is important to not overload the user with the interface. It is important that every design choice is carefully evaluated and, thus, deliberate. Unnecessary features that do not add value can add unnecessary complexity. Moreover, while it is important to make the interaction with the care pathway engaging, the design must not compromise its validity and integrity. It is, therefore, vital to keep the care pathway 'lean' and focus on achieving good usability with few deliberate features rather than detracting from the core purpose of the system.
- **Informed:** To be able to draw valid, scientific conclusions from digital care pathways that aim to improve health behavior, the digital environment should be used to collect helpful metadata. A complete image of a user's interaction is vital for an accurate outcome. Therefore, an 'informed' system collects relevant metadata and context, such as timestamps and device or browser specifics. This information can greatly improve the chances of interpreting the collected data correctly and potentially finding new patterns with artificial intelligence or machine learning methods.
- **Doable.** Applications that serve as digital care pathways often require the user to perform tasks within the system. Those tasks must be realistic in terms of the time and frequency it takes the user to perform them. Furthermore, they should be designed such that the majority of end-users are capable and able to understand and perform the tasks. This is particularly important in the context of digital care pathways as the end-user group consists of people with diverse backgrounds, varying levels of technological abilities, and, potentially, with disabilities. Moreover, as outlined earlier, low user engagement is a common cause of the failure of digital health platforms. Therefore, it is important to design the system such that users do not abandon the system due to its high complexity. A 'doable' design contributes to improved usability and helps to ensure the accessibility of the system.

By following these characteristics, distinct challenges in the design and development of digital care pathways can be overcome. The characteristics are related to each other, and the improvement of one can lead to the advancement of another. For example, gathering metadata creates an *informed* system which in turn can result in producing better outcomes for the users and, thus, increase *validity*.

The VALID framework outlines key elements necessary for the design and development of digital platforms, specifically in the context of digital care pathways. Unlike studies that examine the relationship between various risk factors and aspects of system success, such as the one by Jiang and Klein (1999), the VALID framework does not aim to identify success factors per se. Instead, it functions as a guide to fundamental design aspects that ensure the functionality and user engagement of digital platforms in general and digital health platforms in particular. While Jiang and Klein's work (1999) is centered on the impact of different risks on IS success dimensions, the VALID framework prioritizes collaborative, proactive design and development strategies. This approach shifts from a reactive risk management perspective to a proactive design perspective, emphasizing the creation of digital platforms that are accessible, engaging, and reliable. This focus on incorporating design principles from the outset enables the creation of digital platforms that inherently minimize risks rather than merely managing risks after they arise.

To sum up, the main contribution consists of theorizing care pathways through digital platforms based on our novel findings from co-designing and evaluating the digital platform with professionals and 55 participants, leading to the formulation of the VALID framework to inform the ongoing design and development process of digital platforms of the future. We contribute to the IS literature by theorizing design characteristics of digital care pathways and, thus, further the IS research on digital care pathways design (Ellingsen & Monteiro, 2012; Monteiro et al., 2013; Fitzgerald & Russo, 2005; Fitzpatrick & Ellingsen, 2013). Moreover, through our action design research, we designed and developed a digital platform that serves as a practical contribution and an example of the application of our provided conceptual framework of characteristics of digital care pathways.

6 Conclusion

We co-designed and developed a digital platform for measuring cognitive functioning and presented several learnings from our study that led to the formulation of general characteristics of digital care pathways in the VALID framework. The framework guidelines promote the design of digital health platforms that are scientifically sound (*viable*). They also emphasize *accessible* design that has a wide reach and is available to many people on a variety of devices. In addition, the guidelines include suggestions for a straightforward design that incorporates deliberate design elements to foster engagement without distracting from the core functionality (*lean*). Furthermore, utilizing digital platforms to collect context-relevant data that enables informed interpretations (*informed*) is highlighted. Lastly, the design needs to be *doable* for the users. They need to be able to easily integrate the care pathways into their lives or compliance will suffer. By following this framework, future digital health platforms can strive for improved usability, user satisfaction and compliance, as well as reliable data collection.

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