Game-Based Ergonomic Adaptation of User Interfaces for Online Learning Environments

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Abstract: The standardization of user interfaces makes it more difficult for people with physical or mental impairments to operate software and hardware. Incorrect inputs, longer reaction times, and slower operation are the price to be paid for the standardized appearance. The *ability-based design* approach considers users' individual abilities and adapts the user interface accordingly. This paper presents a computer game to measure cognitive and motor skills, which will be used to adapt ergonomic parameters individually. The adaptation is based on key figures from the tap and pan inputs, summarized in user profiles. In a study with a heterogeneous group of 43 participants, apparent differences concerning the examined abilities could be diagnosed. A larger representation of control objects positively affected hit rate, hit accuracy, and reaction time. More considerable distances between control elements did not necessarily lead to a higher hit rate. Drag'n'drop interactions caused great difficulties for participants with shaky hands. In a case study, we demonstrate the implementation of an adaptive user interface for the Moodle online learning environment. The high individual deviations compared to the whole group underline the need for ergonomically adaptive graphical user interfaces.

1 INTRODUCTION

The standardization of user interfaces (UI) makes it more difficult for people with motor or cognitive impairments to operate software and hardware (Wang et al., 2024; Moured et al., 2024; Castilla et al., 2020; Caldwell et al., 2008). Incorrect inputs, higher response times, and slower operation are the price to be paid for the standardized appearance. This applies to applications for smartphones, tablets, and desktop computers, as they are not only used by the archetypal users to whom attention was paid in the user interface design. The inclusion of broad user groups is a significant concern. For instance, 80 million Europeans (10.7 % of the population) live with one or more types of disability. Many are excluded from using standardized user interfaces of software and hardware applications due to medical conditions or having problems operating them (Naughton, 2017).

This also applies to students in higher education. Firstly, the proportion of students with physical disabilities is just as high as in society as a whole. Secondly, students are reluctant to disclose their impairment to the university and to demand accessible services from lecturers or those responsible for learning applications (e.g., Learning Management Systems (LMS)) (Riddell and Weedon, 2014). Thirdly, online learning is assumed to increase in higher education due to transitions made during the pandemic and the emerging potential of artificial intelligence. Fourthly, distance learning universities are particularly affected because the average age is 10 to 15 years higher than at other higher education institutions (Schmidtmann and Preusse, 2015), and impairments gradually increase with age.

(Wobbrock et al., 2018) presented ability-based design as a promising solution for this problem. This approach focuses on the user as an individual with abilities. Users should not have to adapt to an application; instead, the applications should be adapted to their specific and personal needs and abilities. The user's behavior is analyzed for this purpose. Based on this data, the system can, for example, adapt the user interface according to the user's abilities (Wobbrock et al., 2011). No generalization is made because this would, in turn, exclude many people from using it. Instead, an attempt is made to create a user profile by analyzing individual usage behavior and data from the available input devices, including sensors. As a result, the software or hardware systems adapt their user interface according to the created and con-

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stantly updated user model and provide the user with a personalized and, therefore, more ergonomic user interface.

The approach of *ability-based design* is thus complementary to established methods of *responsive design*. Instead of adapting the user interfaces to the device's requirements (e.g., the display size), the user interface adapts to the user. In contrast to the W3C recommendations for accessible applications (W3C, 2011) and content (Caldwell et al., 2008), the focus of *ability-based design* is not on accessibility for target groups with physical or cognitive limitations but on the promotion of abilities. The approach thus attempts to do justice through design to those target groups who do not perceive themselves as limited. (Wobbrock et al., 2018) points out that people's abilities can be affected not only by disabilities but also by disabling situations. Designing for individual abilities should benefit everyone through more user-friendly and accessible applications.

This paper presents a game that measures cognitive and motor skills for the personalized adaptation of ergonomic features. From the measured values obtained in the game, metrics for specific abilities are calculated and summarized in individual profiles. These profiles are available for the individual adaptation of the user interface in different adaptive systems. A study is presented to determine suitable metrics and value ranges in which 43 participants tested the game under real-world conditions. In a case study, we demonstrate the implementation of a game-based user interface adaptation in Moodle's online learning environment, including game-based adaptation sources.

The remainder of this paper is structured as follows: Section 2 covers related research, Section 3 details game design and implementation, Section 4 discusses data evaluation from a user study, and Section 5 explores adaptive data integration in Moodle. The final section provides conclusions and outlook.

2 REALTED WORKS

A person's limitations and abilities can be roughly divided into vision, hearing, motor skills, and cognition. In terms of abilities, there is also a continuum between non-changing and constantly changing abilities. Adaptation to situational limitations and, thus, changing abilities of users have already been investigated in several studies (Bihler et al., 2009; Perry and Hourcade, 2008). In contrast, longer-term or permanent limitations, while highlighted as important factors influencing UI design (e.g., (Henze et al., 2011)), rarely result in personalized user interfaces for heterogeneous audiences (Kurschl et al., 2012; Kane et al., 2008). Some studies only focus on specific applications such as computer games (Kurschl et al., 2012; Bihler et al., 2009) or recommender systems (Moon et al., 2017), although the collected user data could be used to personalize multiple applications.

Sensor data from mobile devices (Bihler et al., 2009; Paymans et al., 2004), tracking data from the running application (Moon et al., 2017), or user surveys (Gajos and Chauncey, 2017; Parhi et al., 2006) have been used for adaptation before. Tracking data was used to detect a user's handedness, for example. How handedness can affect performance when operating different devices and interaction techniques has been studied several times (Perry and Hourcade, 2008; Inkpen et al., 2006; Silfverberg et al., 2000), but it has not yet been directly translated into adaptive UIs. (Galindo et al., 2018) presented four design options in an adaptive UI. For this purpose, they detected the users' emotional state through facial expressions photographed during runtime. (Henze et al., 2011) took a different approach and collected touch input data from a game app for more than a year to employ comprehensive analyses but not for adaptation. (Gajos et al., 2010) tested the motor skills of experimental participants in a test and adapted the UI of the subsequently examined application according to the test results.

Modeling of adaptation behavior is usually based on key figures calculated from the collected data. For pointing devices like a mouse, touchpad, or touchscreen, the following metrics can be found in the literature: error rate during object selection (Henze et al., 2011), error rate per object size (Henze et al., 2011), processing time of a task (Parhi et al., 2006), ratio of incorrectly processed tasks (Parhi et al., 2006), task hit distribution (Parhi et al., 2006), history of touch movements (Lee and Choi, 2011).

The number of metrics results in a vast design space for the user interface as the target of adaptation (Bouzit et al., 2016). However, the design space should be reduced to a reasonable level in favor of recognizing the familiar UI elements, the ease of use, and the learnability (Paymans et al., 2004). Most of the existing works focussed on the adaptation of individual design elements. For example, the optimal size of control elements has been investigated several times (Bihler et al., 2009; Henze et al., 2011; Parhi et al., 2006), but without considering users' individual abilities. This applies equally to one-handed operation with the thumb (Parhi et al., 2006; Perry and Hourcade, 2008). (Gajos and Chauncey, 2017), on the other hand, have used so-called *Split Adaptive Interfaces* that reserve a limited portion of the screen for quick-launch elements. More comprehensive user interface adaptations consider the placement (Lee and Choi, 2011; Perry and Hourcade, 2008) and orientation (Bihler et al., 2009) of elements as well as the overall layout (Moon et al., 2017; Galindo et al., 2018).

(de Santana and Silva, 2019) presented a client-side measurement of user activities, with the help of the freely accessible data logger WELFIT[1]. Detailed web user data can be continuously collected and automatically analyzed for empirical evaluations.

Over the last two decades, there has been a substantial advance in developing adaptive learning environments (e.g., (Martin et al., 2020). This trend can be attributed to several factors, including the evolving availability of student data, the increasing importance of online learning, the advances in AI, and the awakening awareness of educational institutions to address student diversity (De Clercq et al., 2020). However, in none of these studies and systems was the user interface adapted to improve individual usability, accessibility, or the learner's different cognitive and motor abilities. Therefore, the system proposed in this paper is intended to contribute to extending adaptive learning systems with an adaptive ability-based UI.

3 GAME DESIGN AND METRICS

Because motor and cognitive skills in traditional WIMP (Windows, Icons, Menus, Pointer) interfaces are not measurable or only discernible after extended periods of use, an application-independent computer game that can be played repeatedly and in various contexts is proposed for collecting metric data. Measures are computed and integrated into a user model from the values measured within the game. Based on this user model, adaptations to the graphical user interface of arbitrary WIMP applications can be implemented, enhancing the interaction and accessibility tailored to individual user profiles.

In conceptualizing the game, stringent criteria were adhered to: Initially, the game's theme was curated to resonate with a diverse demographic, ensuring broad appeal and engagement. Subsequently, the game was architectured as a standalone application, capable of seamless integration as a desktop or web app within a spectrum of extant applications, irrespective of their specific functionalities. Lastly, the game was engineered to meticulously capture and process user input data in real-time into a user model. This user model serves as a cornerstone, facilitating the immediate application and refinement of adaptive user interfaces upon the game's conclusion, thereby streamlining the user's interaction experience.

3.1 Game Design

The design of the game was underpinned with a set of design principles (e.g., 'play' as grounded in Social Constructivist Theory, 'challenge' as grounded in Zone of Proximate Development Theory) and design patterns for game design (Björk et al., 2003). The applied design process was based on Fullerton's player-centric four-step iterative design methodology (Fullerton, 2008). This process comprises idea generation, formalization, testing, and results evaluation. Existing browser games, literature about games and game patterns (Björk et al., 2003), and measurable cognitive and motor skills inspired the ideation process in a group of three designers. We defined the following player experience goals: (1) Ensuring players feel challenged but not overwhelmed, keeping them motivated to progress. (2) Encouraging players to maintain concentration and testing their cognitive skills under various scenarios. (3) Creating a game environment that assesses and stimulates fine motor skills through precise controls. (4) Allowing players to feel accomplished upon completing levels. Based on these goals, we formalized the game mechanics (e.g., level structure, core actions, feedback loops, scores) and established rules and constraints (e.g., rules, time limits, and level constraints). We've selected nature as the game's theme because it is a universal topic, especially since many content extensions can be imagined. Different abilities could be measured using appropriate methods by dividing the game app into several games and game levels. The measurement methods, including the resulting data, determined the game's task design. The actions performed by a user playing a game section required repetitions to increase the accuracy of the metrics. Despite this necessary repetition of actions, the game should not appear monotonous. We limited the playing time for each section to provide a certain degree of variety and playful challenges.

The authors and several partly gaming-experienced volunteers playtested early ideas and prototyped games. Feedback from playtesting sessions was continually used to refine and improve the game, ensuring each iteration was better aligned with cognitive and motor skill assessment goals and enhanced the player experience.

Using the *Unity game engine* and the *C#* programming language, a total of three games (see Figure 1)

[1] See the Web Event Logger and Flow Evaluation Tool at https://github.com/IBM/user-test-logger (last accessed 2024/10/29.

were developed with a total of 6 levels.

The first game consists of three levels and is about chasing moles out of the garden. The animals appear randomly at different positions on the screen and have to be hit as quickly as possible. In the process, the user's reaction time is recorded. At the same time, it is tested whether and how accurately the target object was hit. This provides information about the user's hand-eye coordination, attention, and speed. This principle makes it possible to test the factors under different conditions, which is why the objects in the 1st level change in size after hits have been made. The input required is a simple touch on the screen or a mouse click. This model was extended in the second level of the first game, in that a mole must be hit not just once but several times in a row. This additionally allows testing the speed of the hands over a longer period. In order to check how far apart small objects should be, we presented several moles in the third level of which one has to be selected.

In the second game, green and red apples must be placed in the corresponding bucket. By swiping with the finger or dragging while holding down the mouse button, the objects must be moved over a longer distance, some of which are curved and have obstacles. The game duration is limited to 90 or 60 seconds. This allows for testing not only the coordination ability but also the tremulousness and speed of the hand. The size of the displayed objects (in the case of apples) and buttons was adaptively adjusted based on the first game's results. Due to the variable object size, the number of objects displayed simultaneously varied, with no more than 12 apples appearing simultaneously. The coloring of red and green apples in the first level and yellow and blue plums in the second level allowed the detection of the two most common color vision deficits (The National Eye Institute (NEI), 2015).

The task of the last game is to throw stones over the water. Here, the 1st level tests handedness as another important parameter for developing an adaptive, ergonomic design. Handedness can be indicated by the movement of the thumb or mouse on the screen. Recognizing handedness is necessary for one-handed operations because of the limited motion range of the thumb. Important input options could be placed with this knowledge so the user can reach them with the thumb without switching hands or operating the device with both hands. During the second level of game 3, the position of the stone changes in each round. The thumb's range can be determined if the device is held at a fixed position. At this level, coordination and hand and finger dexterity are additionally tested.

3.2 Metrics of Input Data

The game instructions determine the type of input required to manipulate gameplay depending on the game and level. Input is generated by the user when touching the screen or using a mouse. For each input, information is recorded to calculate the required metrics.

The position of a tap on the screen or a mouse click is used to infer whether the target was hit. This way, a hit rate and corresponding standard deviation per object size are derived. For game levels with several potential targets, of which only one may be hit, it is also determined in which of the defined zones the hit was located. Two zones are defined: (1) directly hits the target object, and (2) hits within a certain margin around the object. Other objects are in the second zone, which is directly adjacent to the distance and has the same width as the target object. Since a target is given, the distance between one tap and another can be determined, which is necessary to avoid wrong hits. The hits outside these two zones are treated as slips. If the target was hit, the accuracy of the hit is calculated from the target's center position and the hit's distance. In addition, the reaction time is calculated from the time of the target's appearance and the time of the hit. From the time of the hit and the termination of the input, the duration of the input, the tap or mouse down duration, is determined. At these times, the pressure exerted on the screen is also measured for tap events. If several hits on an object are necessary, the number of hits per second is calculated from the required number and the period over which these were made. The number of errors that occurred during this period is the number of errors per second.

The measures in game two aimed to examine the ability to drag objects over a long distance. To drag an object, the mouse must be moved while the mouse button is pressed for a longer time until the object's destination is reached – this type of input results in a covered distance defined by individual points on the screen. Depending on the device, approximately 60 waypoints per second are recorded. Suppose the frequencies are filtered out of this distance by not considering every waypoint for the distance calculation. In that case, the tremors of the input can be determined based on the ratio of the distances of the covered distance and the smoothed distance. It also results in the calculation of movement speed by considering the duration and distance of the interactions. Using the start and end point, it is determined (1) whether the object has been moved to a destination at all, (2) whether the object was moved to the expected destination, and (3) whether the user applied a strategy to complete the

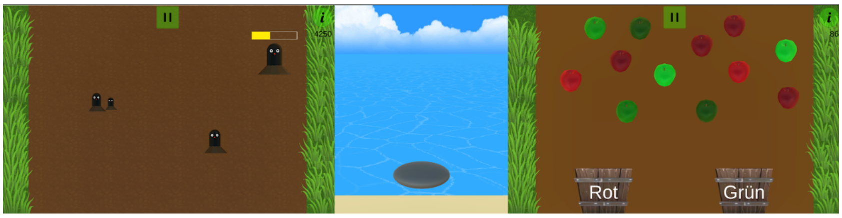

Figure 1: Game scenes: Hitting moles in game 1 level 2 (left), Throwing stones in game 3 (middle), and Sorting apples by color in game 2 level 1 (right).

tasks efficiently (e.g., collect red apples first or collect the nearest apples). In addition, it is stored whether one of the built-in obstacles was touched during the movement.

Analogous to Game 2, Game 3 mandates an extended navigation of the input device across the screen. However, in this tier, the emphasis pivots to the velocity of the swipe gesture. Concurrently, the user's handedness is discerned through the curvature of the swipe trajectory. The orientation of the arcs, whether they open towards the left or the right, indicates the hand employed by the user during interaction.

4 STUDY

The game presented in the last section allows them to capture the motor and cognitive skills of the players. A study was conducted to collect participant data using the game to determine the distribution of the surveyed abilities and identify parameters for adapting user interfaces. For this purpose, 7 hypotheses have been defined. By testing hypotheses 1 to 7, the study aimed to show whether the variance in individual abilities justifies an adaptive user interface design in terms of *ability-based design*. In particular, hypotheses 2–6 aim to identify metrics and ranges of values that can be applied to user interface adaptations.

H1: Smaller objects can be hit less accurately and quickly. The smaller an object is, the more precisely it must be hit with the respective pointing device. Therefore, precise coordination requires more time.

H2: Hand tremor impairs coordination of prolonged pushing movements (Pan). Motor restriction of the hands is manifested, among other things, by slower interactions with pointing devices. A manifestation of this type of limitation is experienced by trembling of the finger, thumb, or hand. Interactions that require a longer pushing movement can, therefore, only be performed comparatively slowly.

H3: The hit accuracy can be improved in terms of response time up to a specific object size. It is assumed that a control element is the optimal size for individual users when the object can be hit accurately within the shortest possible period. Because of the limited space, increasing the size of controls and other objects beyond this, for which there are neither content nor aesthetic reasons, should be avoided. From H3, an individual size for buttons and other touchable objects is given. Consequently, in the design of an application, these sizes should not be set the same for all users but should be adjusted according to individual capabilities.

H4: If the distance between two objects is too small, individual objects cannot be hit accurately. For the design of controls, an individual minimum distance between controls can result from H4.

H5: People with red-green vision impairment can be identified by the error rate in Game 2 Level 1. The user interface can be automatically adjusted for people with color vision loss by adjusting the color scheme and increasing the contrast.

H6: The handedness of users can be determined based on movement patterns. Whether a user is left- or right-handed is a decisive criterion for placing controls (e.g., navigation menus). In smartphone applications, the position of control elements is usually designed for right-handers so that these controls are out of reach of left-handers' thumbs. Even for people with shorter thumbs/fingers, these controls can only be reached by excessive stretching, bending, or reaching around (cf. (Parhi et al., 2006; Perry and Hourcade, 2008)).

H7: Participants' abilities are at different performance levels across all identified metrics. It is assumed that a user's abilities can be assigned to multiple levels. If H7 is valid, adaptation must be performed for every ability measure.

4.1 Methods

4.1.1 Participants

Regarding *ability-based design*, individuals participating in the study were selected regardless of their

Table 1: Measures collected in the three games.

Game	Measure	Description	Range
1	Distance of objects	Distance between two close-by objects that the user should not confuse.	[0,N]
1	Size of objects	Area of an object to be clicked on.	[1,N]
1	Repetition of clicks	Number of clicks on an object.	[1,N]
1	Decision between objects	Time needed to decide between several objects to be clicked.	[0,N]
1	Hit accuracy	Accuracy at which a click hits an object.	[0,1]
1	Object processing rate	Number of objects (e.g., moles in game 1) per time.	[0,N]
2	Points per second	Achieved points per second playtime.	[0,N]
2	Tremor rate	Amount of tremor measured during drag and drop movements.	[0,1]
2	Green-blue objects	Total number of green or blue fruits assigned to a basket.	[0,N]
2	Green-blue correct objects	Number of correctly assigned green or blue fruits to the corresponding basket.	[0,N]
2	Red-yellow objects	Total number of red or yellow fruits assigned to a basket.	[0,N]
2	Red-yellow correct objects	Number of correctly assigned red or yellow fruits to the corresponding basket.	[0,N]
2	Hit accuracy	Accuracy at which a click hits an object.	[0,1]
3	Right hand used	Number of times the right hand was used.	[0,N]
3	Left hand used	Number of times the left hand was used	[0,N]
3	Hit accuracy	Accuracy at which a click hits an object.	[0,1]
3	Object processing rate	Number of objects (e.g., moles in game 1) per time.	[0,N]

chronological age, gender, or individual frequency of use of smartphones, tablets, or computers. In particular, students and adolescents of a school for physically impaired people have been asked to participate voluntarily. Forty-three individuals participated in the study, of whom 23 were male and 20 were female. The average age was 31.2 years (SD = 21.0). The distribution by age and sex, as shown in Fig. 2, represents the distribution of age and sex at the school. The participants reported information about gender, age, and known physical or mental impairments. 14 individuals reported having difficulty operating mobile devices during a personal interview.

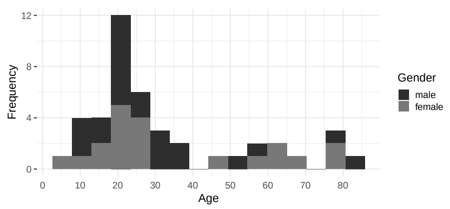

Figure 2: Age distribution of participants by gender.

4.1.2 Procedure

For the two-week implementation phase of the study, the application was made available for the platforms iOS (TestFlight from the App Store), Android (via PlayStore and .apk file), Windows, Mac OS X, Linux, and as a web version using WebGL. Using different end devices with various input and output options thus enabled realistic study conditions.

The study participants acted independently and did not perform specific tasks. Instructions and assistance were not provided. The participants installed the application on their private computer devices and played through it once. The execution of the game took about 10-15 minutes and consisted of the three games described in section 3.1. The participants could contact the experimenter via email if they had any questions or problems. A total of 6 participants did not complete the game. Their data was not included in the evaluation, so in the end, data sets from 43 participants could be evaluated.

Five participants used a computer to complete the test. Inputs on the desktop computer were made faster and with a lower variance. Consequently, there was no need to increase the distance between objects. Twenty-six participants held their mobile device in their hand throughout the game, 12 changed position during the games, and only one participant left the device on a flat table. Only five mobile devices had a pressure sensor, so no analysis of this data was performed.

4.2 Results

The presentation of the results is structured in accordance to the previously established hypotheses.

As shown in Fig. 3, the accuracy with which an object was hit is positively monotonically related to the size of the objects ($r = 0.31$, CI 95 % $[0.21, 0.40]$, $p < 1e-6$). The relationship between reaction time and object size turns out to be smaller and monotonically negative ($r = -0.26$, CI 95 % $[-0.35, -0.15]$, $p < 1e-6$). Since smaller objects can be hit less accurately and quickly, H1 is confirmed.

The number of apples and plums put down in the second game was negatively monotonically related to the Amount of trembling detected while moving these objects ($r = -0.38$ CI: 95 %, $[-0.55, -0.18]$, $p < 1e-3$). The more tremulous the hand was while shifting, the fewer objects could be shifted to the intended position during playtime. This relationship is shown in Fig. 6. In addition, there was a higher variance of this value with increasing tremulousness ($r = 0.78$ CI: 95 %, $[0.68, 0.85]$, $p < 1e-6$). H2 can thus be considered as confirmed.

However, in Fig. 4, one can see how participants could hardly improve their reaction time for object sizes larger than 52 pt. The quotient of mean hit accuracy and reaction time helps determine individual performance as a function of object size. The more accurately an object is hit and the less time it takes, the higher the quotient. For objects between 52 pt, and 60 pt, the quotient increases the most (Fig. 5).

As depicted in Fig. 7, most participants (31) cope well with the smallest object size, although for 12 individuals larger controls should be offered. For these 12 individuals, the quotient could be improved on average by 74.24 % (SD=14.55) compared to the minimum size of 44 pt. From this, it can be concluded that the hit accuracy and reaction speed can be individually determined up to the object sizes considered here and that H3 is thus fulfilled.

Regarding H4, only a minimal correlation between the distance between two objects and the hit rate could be found. H4 is therefore discarded. Thus, with the help of the applied elicitation method, no requirements for a personalized user interface design can be found.

Regarding the test of H5, a red-green visual defect was reported by one person without being asked. This person incorrectly sorted 38.2 % of the red apples and approximately 10.5 % of the green apples. In contrast, the other participants correctly assigned an average of 98.2% (SD=3.9) for the red apples and 97.8% (SD=3.0) for the green apples. After consultation with the participant, it turned out that the lat-

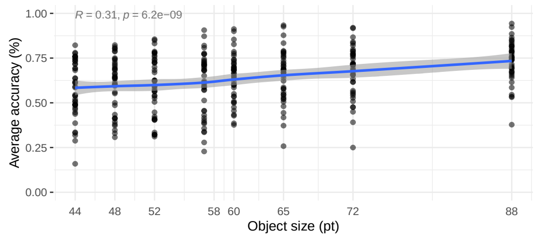

Figure 3: Correlation of the accuracy of hits and the size of controls.

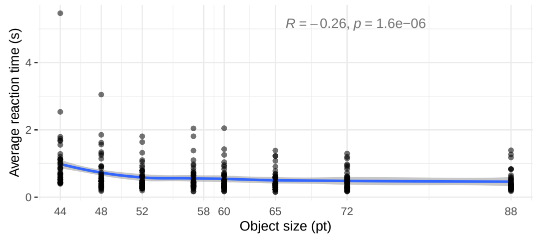

Figure 4: Correlation of the mean response time and the size of control elements.

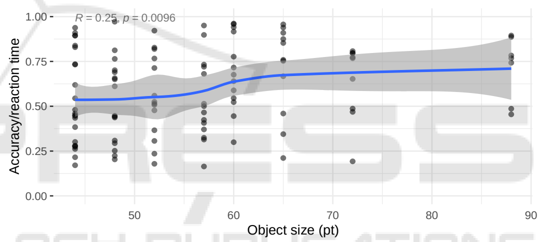

Figure 5: Accuracy per reaction time for different object sizes.

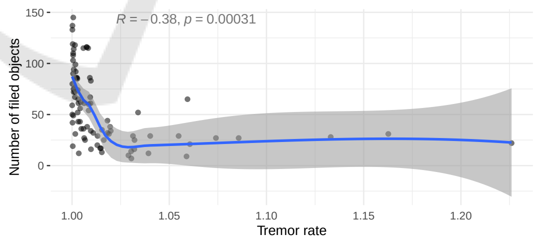

Figure 6: Correlation of the mean individual tremor rate and the number of successfully moved and deposited objects.

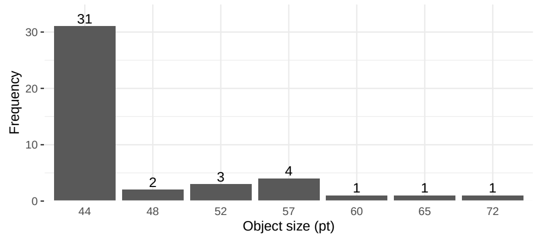

Figure 7: Histogram of optimal object sizes.

ter could distinguish the lighter shades better than the darker ones. For the darker ones, guessing was predominant. After the colors were changed to blue and yellow at the next level, the mentioned participant had no more difficulties sorting the colors. The hypothesis H5 can be confirmed for this participant but still requires a more comprehensive investigation with more persons with corresponding color vision deficits.

According to the evaluation of the pan patterns of the third game, approx. 20 % of the participants were classified as left-handed. For 30 participants who used a mobile device and were consulted afterward, the handedness of 8 left-handers and 22 right-handers could be correctly identified. The information can be more accurate for mobile devices since the hands/fingers interact directly with the screen compared to indirect input devices such as a mouse.

To test H7, the metrics mentioned up to this point correlated. Fig. 8 shows high positive correlations for related measures in different game levels. For instance, the hit rate, accuracy, and reaction time correlated between levels 1.1 and 1.2. As expected, color vision impairment and handedness show a very low or no correlation with any other measure. A high tremor affects a higher reaction time and tap duration, while the hit rate is lower, and the outer areas of an element are hit more often than the element itself. H7 can be confirmed.

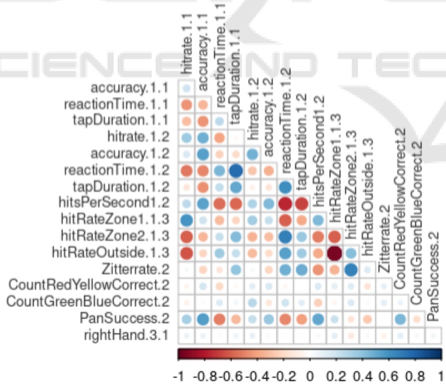

Figure 8: Correlation matrix of used metrics indication positive (blue) and negative (red) correlations.

4.3 Discussion

The casual data collection during the games enabled the creation of meaningful user profiles. The research design implied the freedom of choosing a hardware device. This led to a mixture of input data from touch displays and other unknown input devices, which had little statistical impact.

The results show a relatively low internal validity since controlling how the users played the game was impossible. However, it could be ensured that the participants could complete the game within a considerable time range. The comparatively small number of participants and various devices also indicate a relatively low external validity. This is particularly evident for testing H5 and H6.

Since participants played the game only once, the results of the first moves per level are biased by learning effects. We tried to compensate for this effect by repeating the moves several times. However, this corresponds with a real-world application of the game.

Another limitation of the study is the partial self-selection of participants. The comparatively high proportion of 20-30 year old is due to the participation of students, who are an exceptional group in their own right. The participation of the 14 children and adolescents with demonstrable motor impairments did not form a representative group of the overall population of Germany. Nevertheless, the study succeeded in including a heterogeneous group of participants based on their age and ability to use the pointing devices.

5 GAME-BASED USER INTERFACE ADAPTION IN MOODLE

The study in sections 4 has shown which motor and cognitive abilities can be precisely recorded with the help of a computer game. Taking these results as a reference, threshold values could be defined for mapping adaptive components in a UI. In the next step, these adaptation sources have been transformed into concrete adaptation targets so that an application's design adapts to its users' motor and cognitive abilities.

The learning management system Moodle has been utilized to showcase the functionality of an adaptive user interface through a specifically designed plugin. This plugin is committed to supporting both individual reading and collaborative engagement with extensive course texts, thereby illustrating the potential of Moodle to host and enhance such adaptive educational interventions.[2]. In distance learning at FernUniversität in Hagen Germany, a nuanced approach to reading has been employed over two years, leveraging a comprehensive suite of tools within Moodle. This suite encompasses a table of contents, an in-text search function, text marking facilities, bookmarks, and the integration of personal annotations and public discussions. These features enrich the reading experience, fostering a more interactive and engaging

[2]See https://github.com/CATALPAresearch/mod_longpage/ (accessed 2024/01/23).

learning environment. All reading activities in terms of scrolling text sections into the screen's visible area are captured using the intersection observer API of the web browser.

After entering a page with reading material, the game was promoted to the users in a modal dialogue. Referring to the Pomodoro method, after an active reading time of 25 minutes, we offered students to take a break and play the game. In addition, the game could be started on demand from the side menu.

As the main target of the UI adaptations, the size of the font and control elements have been chosen (Tab. 2). Tab. 2 shows the metrics and targets with their respective value ranges. The individual average measures from the game were stored in the Moodle database. The client processes the adaptation of the user interface based on this data. Using Vue.js, including the VUEX design pattern, the adaptations become immediately visible to the user. Examples of resulting UI changes are shown in Fig. 9 and 10. Continuous adjustments in the target system were necessary to keep the metrics current even after the game was finished. For this purpose, similar to the game, the object hit rate, click time, and shakiness were captured throughout the Moodle system. This data was calculated using the game data. In this way, intra-subject differences could be compensated. Short-term health limitations, for instance, could be considered in the adaptive design.

Moodle usage involves significantly fewer clicks per unit of time than the game presented here. This lower frequency of click interactions is insufficient for continuously and reliably adjusting metrics, highlighting the effectiveness of our approach: utilizing an alternative application, such as a game, to capture motor and cognitive abilities.

One of the most challenging aspects was redesigning the text highlighting method. The current solution, which involves setting the start point of the highlight with a click and then extending it using keyboard arrow keys, is only functional on devices equipped with a keyboard.

The adaptation of the UI presented here constitutes a minor modification within Moodle, specifically limited to a single plugin. To entirely reshape the UI of the entire LMS, a significantly greater effort is required to ensure consistent display across various devices. This exploration into UI adaptability within Moodle presents a foundational step in enhancing user interaction, particularly in learning environments where cognitive and motor skills measurement is crucial.

The adaptive UI was tested in a think-aloud test with five volunteer students: two younger persons without known impairments and three older students who generally reported mild cognitive impairment when accessing Moodle web content, mainly because of visual impairment and/or tremors. All participants liked to play the game and were able to complete it. While two younger participants did not perceive any differences in the (unchanged) Moodle UI, the remaining participants appreciated the increased size of icons and fonts in the adapted version.

6 CONCLUSION AND OUTLOOK

In this paper, we have shown a way to measure the motor and cognitive skills of users using a computer game and to be used to adapt the user interface of arbitrary applications. The suitability of measures of hit rate, reaction time, hits per second, tremor, movement speed, color vision ability, and handedness was evaluated in a study with 43 participants. The analysis of the recorded data and the testing of the hypotheses made clear that each user is an individual and, therefore, personal abilities should be considered in the design. In a case study, the *ability-based design* approach was implemented for the adaptive design of a Moodle plugin.

A game-based adaptation has several advantages and disadvantages. For example, skills can be determined in a time-saving and more precise way compared to sometimes one-time or infrequent user interactions with controls that may be too small. Repetitions cannot level outliers in measurements in applications like Moodle if the natural user interactions do not allow repetitions to occur. Handedness and color vision usually cannot be captured through ordinary user interactions but only through artifactual interventions such as CAPTCHA[3] tests. Continuous data collection can also affect the application's performance. Realizing the principle of data sparsity is an open question of which capabilities require continuous or at least regular adjustment.

Nevertheless, a collection of properties through a game represents a media break to the target application to which the user interface is to be adapted. It may not seem appropriate to integrate a game in every type of application. Since the capabilities are not measured in the target application, the measured values must be converted from the game to the target application's UI. For this conversion, the game's values can serve as a baseline, but they do not replace a calibration. To better account for intra-subjective fluc-

[3] Abbreviation for Completely Automated Public Turing

Table 2: List of UI elements that have been adapted based on initial measures from the game.

Element	Adaptation	Range	Measure
Control elements	The size of control elements and the font size of the text change adaptively.	$\{44, 48, 52, 58, 60, 65, 72, 88\}$ (pt)	Game 1: size of objects, hit accuracy
Object distance	For better differentiation of controls like buttons and links, their margin is adapted.	$\{2, 4, 6, 8, 10\}$ (px)	Game 1: distance of objects, hit accuracy
Color combinations	To address color blindness, the style sheet of Moodle has been adjusted. Furthermore, CSS image effects are used to convert colour-mismatching images.	$\{default, red\text{-}green, blue\text{-}yellow\}$	Game 2: red-yellow correct objects, green-blue correct objects
Menu	For left-handed people, the main menu is moved from the right to the left side of the screen.	$\{left, right\}$	Game 3: left hand used, right hand used
Text marking	With shaky mouse movements, text passages are marked not by point and expansion but by the keyboard.	–	Game 2: Tremor

Figure 9: Baseline without UI adaption.

Figure 10: Adapted UI with larger font size, bigger icons, and increased margin between the icons.

tuations in adaptation, a continuous, albeit less precise, measurement of cognitive and motor skills is needed in addition to the game. However, longer-lasting investigations in the field are required to investigate these fluctuations and their influence on an application's usability.

Therefore, the adaptive system presented in section 5 will be used in teaching in the coming months. Students should be able to use the game as often as they want while their input operation is continuously recorded. In this way, we would like to determine the effect size in a single-case research design using nonoverlap techniques (Parker et al., 2011). From a technical perspective, we see adaptive ability-based design as a component of our adaptive learning environment based on Moodle.

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tests to tell Computers and Humans Apart.

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