D3.3.2 & D3.3.3 Gaze Interaction & Analytics

Work package	**WP3 Multimodal Analytics and Assessment**
Task	**T3.3 Gaze Interaction and Analytics**
Editor	**Lucas Paletta (JRD)**
(co-)authors	**Martin Pszeida, Amir Dini, Sandra Schüssler, Anna Jos**
Public / confidential	**public**

Project PLAYTIME

The research leading to these results has received funding from the AAL Programme of the European Union and by the Austrian BMVIT/FFG under the Agreement no 857334, ZonMw (the Netherlands) and funding from Brussels (Belgium). It reflects only the author's view and that the Union is not liable for any use that may be made of the information contained therein.

31/08/20

Document information

Reference	D3.3.2 & D3.3.3 Gaze Interaction & Analytics
Version	Final
State	Finalised
Date	31.08.2020

PLAYTIME partner			organisation
01	JR		JOANNEUM RESEARCH Forschungsgesellschaft mbH DIGITAL – Institut für Informations- und Kommunikationstechnologien, 8010 Graz
02	SVD		Sozialverein Deutschlandsberg Kirchengasse 7, A-8543 Deutschlandsberg
03	GGZ		Geestelijke Gezondheidszorg Eindhoven en de Kempen Postbus 909, 5600 AX Eindhoven, The Netherlands
04	TIU		Stichting Katholieke Universiteit Brabant, Tilburg University PO Box 90153, 5000 LE Tilburg, The Netherlands
05	MCR		McRoberts BV. Raamweg 43, 2596 HN The Hague, The Netherlands
06	MBY		MindBytes F. Roosseveltlaan 348-349, B8, 90600 Ghent, Belgium
07	GEU		Ghent University Sint-Pietersnieuwstraat 25, 9000 Gent, Belgium

Acknowledgement:

The research leading to these results has received funding from the AAL Programme of the European Union and by the Austrian BMVIT/FFG under the Agreement no 857334, the Netherlands Organisation for Health Research and Development (ZonMW) and the Flanders Innovations & Entrepreneurship (VLAIO).

Contents

1 Executive Summary

Eye tracking provides a useful methodology for monitoring changes in cognition and giving fundamental insight into human behaviour by detecting executive deficits detected in Alzheimer's disease for example using the anti-saccade task. This approach has a number of advantages over traditional methods of psychological assessment. Objective of this deliverable performed by JRD is the provision of analytics about relevant diagnostic features gained from eye movements and dependent behaviour analysis.

Features about characteristics of interaction were captured in the context of executive functions following the outline of Deliverable D3.3.1. This report provides a combination of two Deliverables, i.e., D3.3.2 and D3.3.3, integrating all contributions of the project in this context, and providing the conference publication that summarises the complete software development.

2 Motivation and Overview

The description of the motivation as well as the basic concept behind the attention training is described in Deliverable D3.3.1. Attention training is represented in PLAYTIME by means of the module „Mobile Interactive Retrieval of Attention" (MIRA). In Deliverable D3.3.1, the principal serious game content has been presented in particular in Section 6.1 (Attention games with MIRA).

In the following, we refer to novel aspects that led to the MIRA version for the main field trial and to the publication at the ETRA conference that is part of this Deliverable.

3 Technical Description MIRA

3.1 MIRA: Mobile Interactive Retrieval of Attention

The overall concept of the MIRA framework is depicted in Figure 1. MIRA provides a playful framework of serious games, MIRA is driven by emotional narratives to motivate gaze based interaction. The module provides analysis of eye movement features in order to investigate attention in cognitive control when interacting with the user interface. Statistical analytics are mandatory to classify stages of mental disorder on the ground of machine learning solutions.

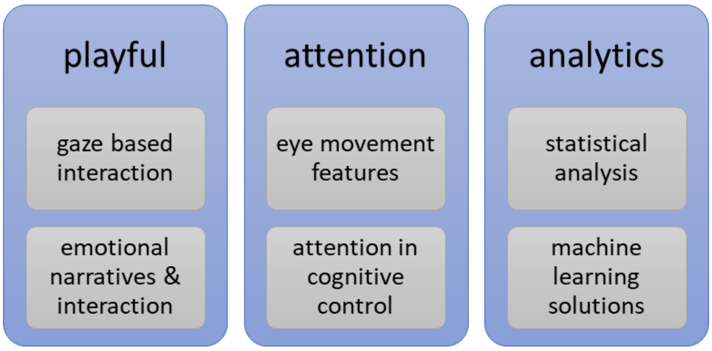
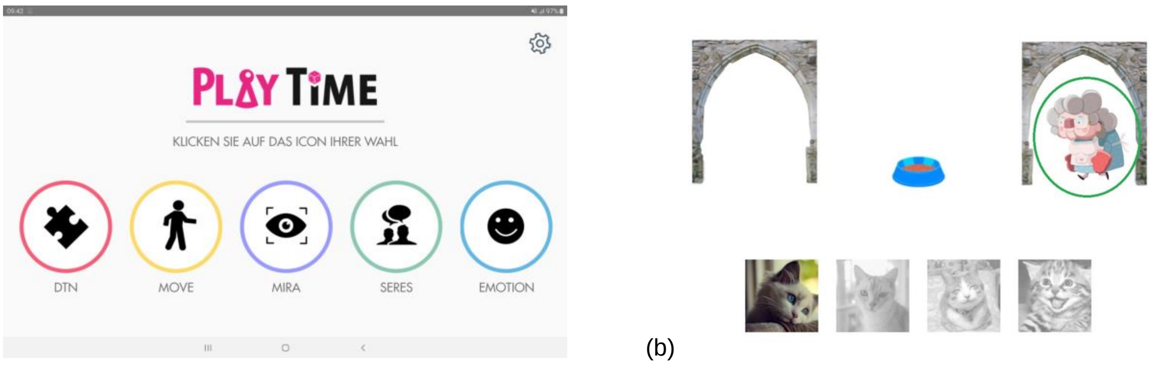


Figure 1. Concept of the MIRA framework. The serious game component consists of three major modules, i.e., the serious game aspect ("playful"), the attention related aspect including the logging of the eye movements ("attention"), and the analytics module which interprets the data captured from the patients' sessions.

Figure 2 depicts the location of the MIRA button on the PLAYTIME dashboard for the triggering oft he MIRA component as well as a characteristic MIRA serious game appearance.



(a) (b)

Figure 2. MIRA button on the PLAYTIME central component dashboard (left) and characteristic MIRA serious game appearance (right).

3.2 System Architecture

Figure 3 shows a schematic overview of the MIRA system architecture. A launcher app includes a web environment for calibration, webcam-based eye tracking, serious game in the sense of neuro-psychologically motivated attention training, and an archiving mechanism for integration into the PLAYTIME environment.

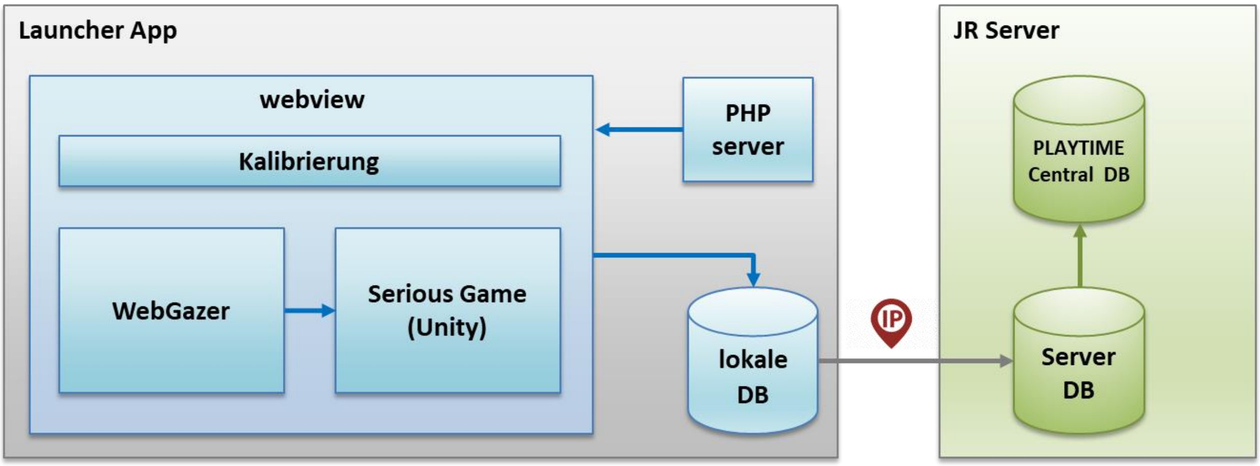


Figure 3. System architecture of the MIRA Serious Game installation.

3.3 System and Functionality

The Serious Game in MIRA is a WebGL application developed in Unity. Together with the WebGazer (Sec. 3.8) environment, these components are included in a web environment (programmed in HTML & JavaScript). This web environment is displayed using a PHP server application. The PHP server application is automatically initiated at Tablet startup. The web environment is controlled by the launcher application of PLAYTIME and displayed in a web view.

The central component for reading eye movements is the WebGazer. This is initialized in the web environment and the corresponding WebGL application is loaded. After successful loading, the WebGL application is temporarily hidden. This is a prerequisite for starting the calibration of the WebGazer by analyzing individual eye movements.

The calibration routine is a JavaScript function that presents a series of predefined calibration targets to the user one after the other. These targets are presented in the form of 24 animated flowers for the special target group of dementia patients. The user is asked to fix calibration targets with his/her gaze and confirm them by touch inputs. These values are passed on as training input to an algorithm of the WebGazer, which estimates the mapping of the estimated gaze orientation to concrete display coordinates in an error-minimizing way in the context of a machine learning process. After successful calibration, the web contents of the routine are hidden and the actual "serious game" is brought back to the foreground.

The "Serious Game" consists of individual game units, each with an individual narrative in the context of a typical evaluation of human gaze behaviour, i.e., the anti-saccade test. During the completion of game units, certain "stimulus events" are generated via Unity and at the same time the raw data of the current gaze behaviour is calculated by the WebGL application. The gaze values thus obtained are used to control & evaluate the game and as a basis for the calculation of gaze characteristics for the final evaluation of human attention.

The results of this evaluation as well as the raw data of eye tracking and data of stimulus events are stored locally on the tablet at the end of a game unit.

When MIRA is terminated, the upload of all relevant data to the PLAYTIME file server is started via the launcher application. Selected, potentially neuro-psychologically characterizing results of the gaze behaviour are finally inserted into the central database of the PLAYTIME application.

3.4 Eye Movement and Data Analysis

After successfully running a MIRA game unit, two data sets are generated locally on the Tablet PC as follows:

Data set 1 (features of gaze behavior):

- **UserID: <string>** - the login ID that was set for the Launcher App
- **Date: <string>** - local (on tablet) date, on second.
- **UnitNo: <int>** - Which topic was played.
- **OutcomeScore:** <int> [0..10] - How many points (score) were reached.
- **EyeTrackingErrorRate:** <float> [0..1] - How many errors were made, if a "gaze reset" was detected. "gaze reset" here means that we have detected glances at the screen between the stimuli for at least 1 second.
- **EyeTrackingPSA:** <float> [0..1] - How many of the glances fell on the pro-saccade-area if stimuli were visible.
- **EyeTrackingASA:** <float> [0..1] - How many glances fell on the anti-saccade area when stimuli were visible.
- **GazeResets:** <int><int> to be ignored for the moment.
- **GazeQuality:** <float>[0..1] - How many times, over the duration of the task, the eyes of WebGazer were detected within the sub-area defined by WebGazer (rectangle that turns green/red during calibration if you have head in area/not in area) in the video frames of the camera stream.

Data set 2 (raw data):

- UserID: <string> - the login that was set for Launcher
- Date: <string> - local (on the tablet) date, on second.

followed by:

Series of integer triples <int>;<int>;<int>, these stand for:

- milliseconds_time (since WebGazer started)
- gaze x cord (px) [0-1280]
- gaze y cord (px) [0-800]

and after the update of 18.10./21.10.2019, as follows,

Stimulus events when they occur: <string>;<int>;<string>;<string>, these stand for:
- "stimulus" string, so we know these are not gaze readings.

- milliseconds_time (since start of WebGazer)
- Whether it's a "good" stimulus: True/False
- Whether this stimulus appeared on the left: True/False

3.5 MIRA User Manual

For a better acceptance and understanding of the MIRA module a manual was developed (see Figure 4). It offers a step-by-step introduction into the use of the hardware (Tablet PC and web camera) as well as into the MIRA software usage.

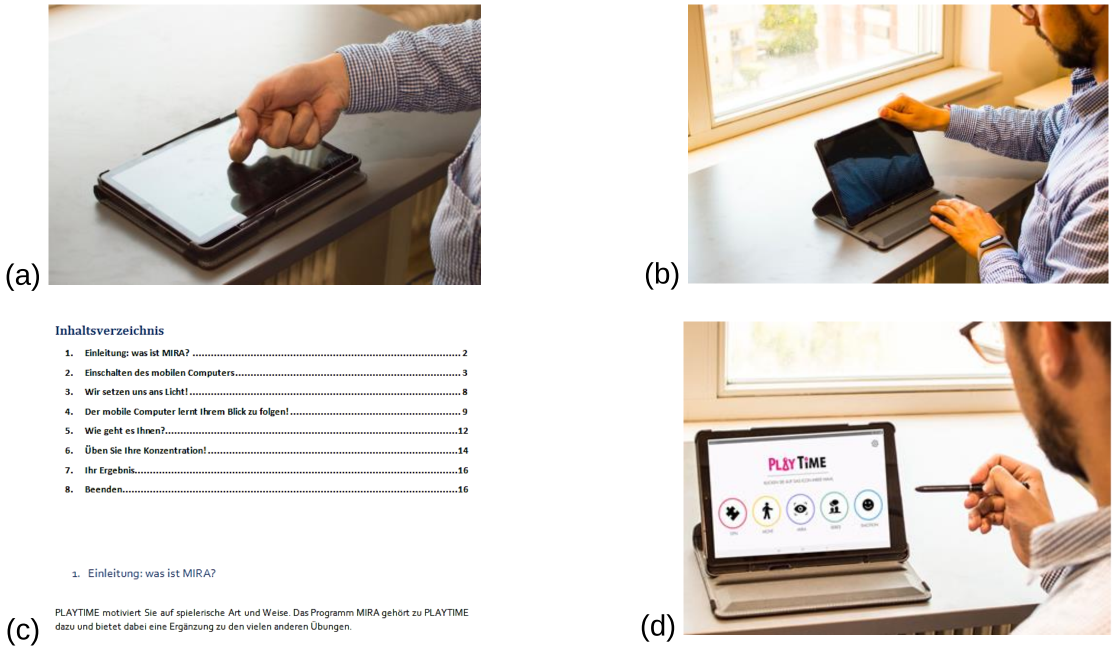


Figure 4. The manual for the MIRA module for a better acceptance and understanding.

Figure 5 depicts a collection of motivating attention games of the MIRA component. The games are related to activities of daily living (ADL) that are of central importance to the target user group. The graphics design was evaluated by trainers in order to avoid inappropriate game content and appearance.

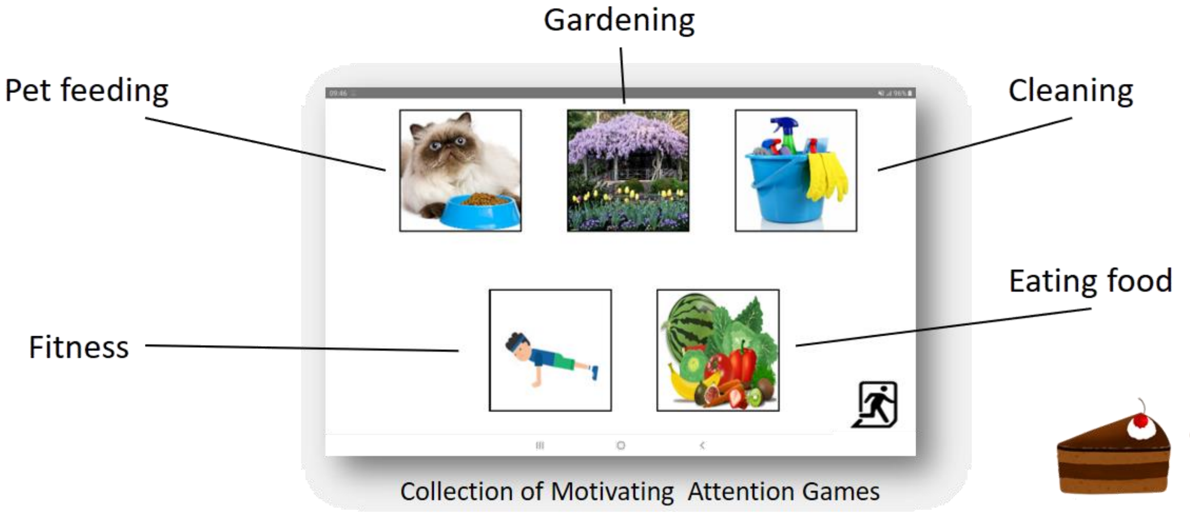
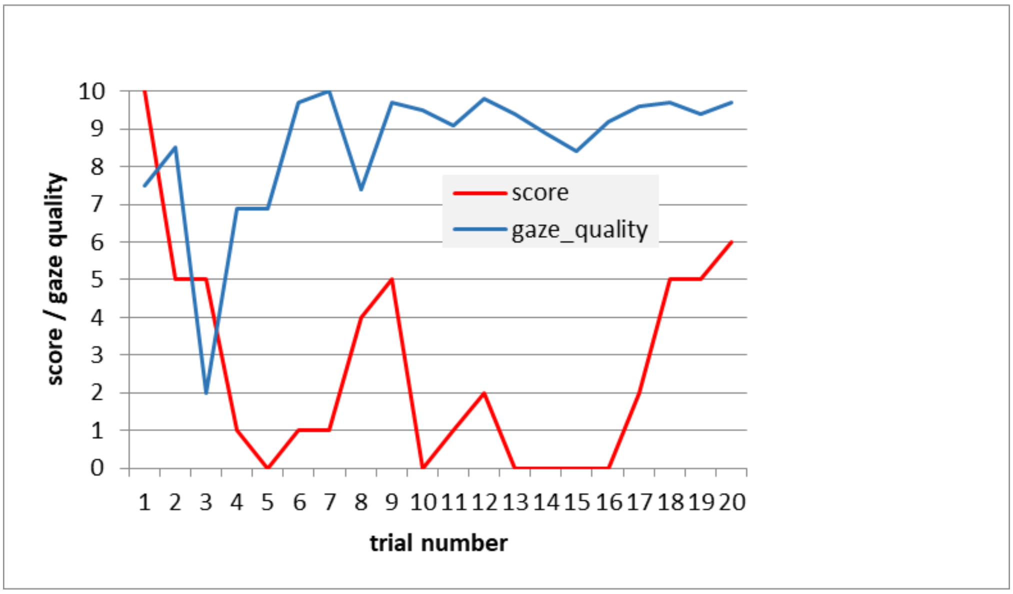


Figure 5. Collection of motivating attention games of the MIRA component.

Figure 6 depicts a possible configuration of MIRA scores in terms of feedback to the actual game performance.

Figure 6. MIRA scores in terms of feedback to the actual game performance.

Figure 7 demonstrates the score performance over several weeks. People with MMSE below 30 have a difficult time understanding the game mechanics so that one concludes that the configuration is mainly suited for

(a)


(b)


Figure 7. MIRA scores and gaze quality of two typical Austrian users: (a) age 71 years, MMSE 30, diagnosed with Alzheimer, (b) age 83 years, MMSE 26, diagnosed with Alzheimer.

Behavioural changes are possible through reinforcement, if authentic and realistic tasks are used. Interventions based on this approach show the history of a problem, behaviours to solve that problem and the consequences of those behaviours, and repeat this cycle until learners recognize connections between those histories, behaviours and consequences. This approach is therefore also called the ABC approach and can simulate real and complex problems with multiple links, which is consistent with informal carers of people with dementia (Houts, Nezu, Nezu & Bucher, 1996).

3.6 Game Concept Antisaccade Test

Figure 8 shows the scenario of the MIRA Serious Game in analogy to the methodology in the "Anti-Saccade Test". The scenario contains two portals (Figure 7a), in which random "avatars" can appear. These are related to activities that are performed on an object in the centre (feeding bowl) and thus have an effect on the state (example: state of happiness of a kitten, below). (Figure 7b) Activation of a "negative" avatar causes a relapse into a lower state (kitten unhappy). Therefore this avatar should not be activated. (Figure 7c) Activation of a "positive" avatar causes the progress to a higher state (kitten happy). Therefore this avatar should be activated. (Figure 7d) Other analogous problems from everyday life, such as repelling snails to maintain a vegetable bed, are included in the games collection.

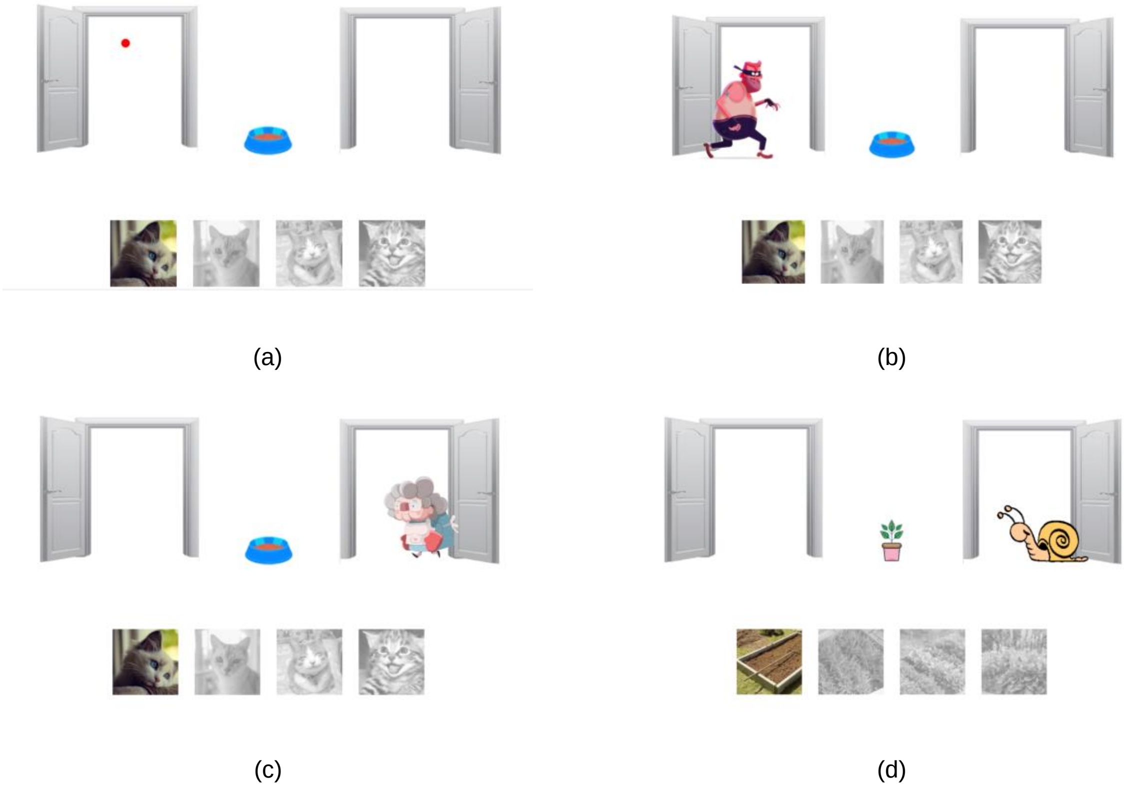


Figure 8. Scenario of the MIRA Serious Games in analogy to the methodology in the "Anti-saccade test". (a) Portals for the appearance of "avatars" and status display (below). (b) Activation of a "negative" avatar. (c) Activation of a "positive" avatar. (d) Analoge problems from everyday life.

3.7 MIRA - Final Evaluation

The data were captured from the main field study, receiving data from 15 elderly with M=81.7, S=4.6 years of age, 91.7% females, all diagnosed with Alzheimer's disease and mental state MMSE M=25.4, S=3.1, Montreal Cognitive Assessment (MoCA) score M=17.9, S=4.5 and Clinical Dementia Rating (CDR) M=1.0, S=0.7.

PwD used MIRA (see Figure 9, including video link) within 10 weeks M=6.2, S=4.1 times, they were introduced and assisted by trainers, some learned to play alone. During M=86.3% of playtime users were frontally centered and gaze was estimated. Table 7 depicts most important correlations between the MIRA outcome measures and dementia rating scores. Applying second order polynomial regression enabled to estimate MoCA scores from MIRA outcome scores with an error of M=2.6, S=1.9 MoCA points.

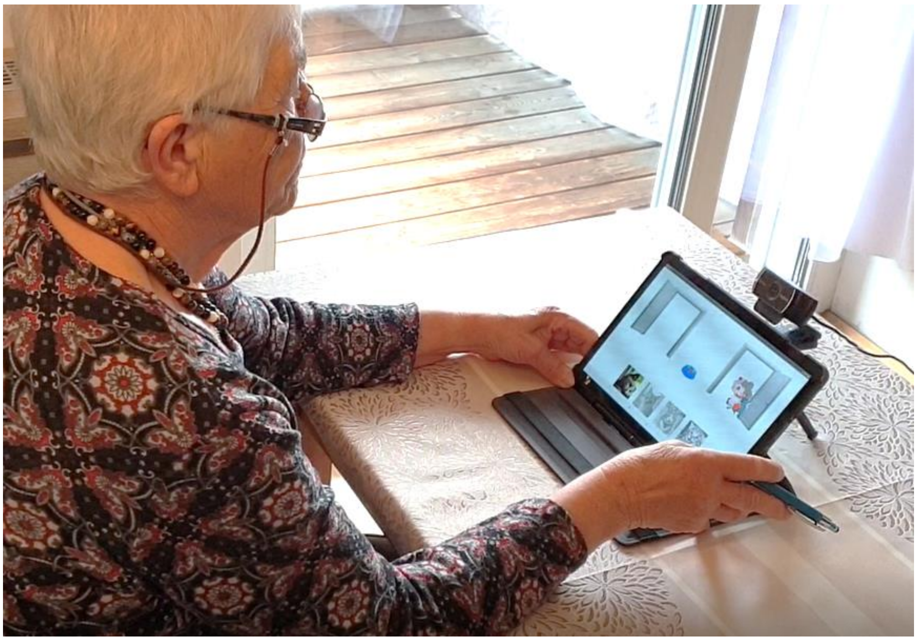


*Figure 9. A person with Alzheimer's disease plays PLAYTIME component **MIRA**, a serious game version of the "anti-saccade" task. A video about the MIRA app and analytical results (Paletta et al., 2020) can be viewed at this link.*

Table 7 presents an overview on most relevant correlations between MIRA game score and neuropsychological assessmsnet score as well as for executive function related scoring in the context of "activities of daily living" (ADL). Particularly high correlations are found[1] between

- Game score (mean score) and MoCA total score (r=.713**)
- Game score (mean score) and MoCA subscore "Visuospatial Executive" (r=.729**)
- Game score (mean score) and MoCA subscore "Language" (r=.711**)
- Game score (mean score) and MoCA subscore "Naming" (r=.559*)

[1] "*" represents p-value < .05, "**" represents p-value < 0.01.

- Game score (mean score) and B-ADL "Drink preparation" (r=-.608*),
- Game score (mean score) and B-ADL "Using the toilet" (r=-.589*),
- Game score (mean score) and B-ADL "Transferring" (r=-.586*),
- Game score (mean score) and CDR (r=-.695**),
- Game score (mean score) and CDT (r=.607*)

Table 1: Statistically significant correlations (Spearman's Rho) between MIRA outcome measures and dementia rating scores.

MIRA parameter	***dementia rating score***	***Spearman's Rho***
mean MIRA outcome score	**Clinical Dementia Rating** (CDR)	-.695**
	Clock-Drawing Test (CDT)	.607*
	Montreal Cognitive Assessment (MoCA)	.713**
	MoCA-1 **Visuospatial** Executive	.729**
	MoCA-3 **Language**	.711**
	Bristol **Activities of Daily Living Scale** (B-ADL): Drink preparation	-.608*
	Bristol **Activities of Daily Living Scale** (B-ADL): Transferring	-.586*

We conclude from these results, firstly, that we have a rather small but valid study population (N=15) but still a good basis for a substantial first estimate. The correlation results, which are high in value (r > .6), in particular, relating to the MoCA but also to the CDR are **very significant** (p-value < .01). Furthermore, there are statistically significant correlations with MoCA, subscores, CDR, CDT and B-ADL which points to the strong hypothesis that the MIRA definitely captures fundamental statistics about the **cognitive status**, but even more, about **executive functions** that are in relation to the B-ADL scores.

Based on the highly correlated characteristics, estimates for the current degree of dementia can then be derived. Figure 10 shows the data from the evaluation of the Serious Game based estimator to predict the overall MoCA score. The estimates based on a polynomial regression (y = -0.9672 x2 + 8.0319 x + 5.4096; see Figure 10) give a mean error of the estimate of 2.60 (standard deviation 1.93).

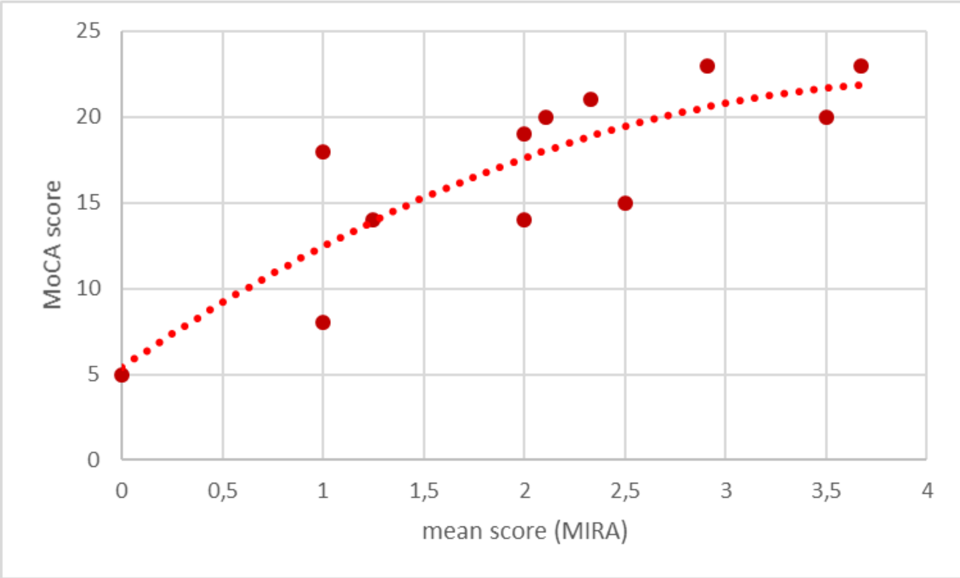


Figure 10. Correlation between MIRA game data and MoCA-supported estimators of the degree of dementia. The polynomial estimator achieves an average accuracy of 2.60 ± 1.93.

Table 2. Evaluation of the Serious Game based estimator to predict the overall MoCA score.

User ID	SG Result	MoCA	estimator y=f(x)	error (y)
1	2	24	19	5
2	2,88	19	21	2
3	3	26	22	4
4	1,25	14	15	1
5	3,67	23	22	1
6	2,11	20	19	1
7	3,5	20	22	2
8	1	18	13	5
9	2,91	23	21	2
10	2	19	19	0
11	2	14	19	5
12	0	5	5	0
13	2,5	15	20	5
14	1	8	13	5
15	2,33	21	20	1
Mean	2,14	17,93	18,00	2,60
Standard deviation	0,77	4,49	3,47	1,93

3.8 WebGazer License

The central component "WebGazer" for the webcam-based estimation of gaze orientation ("eye tracking") was adopted in MIRA by the Computer Science Department (HCI group) of Brown University, Washington, D.C.

"WebGazer.js" is an eye-tracking library that uses common webcams to derive the viewing angle positions of web visitors on a page in real time. The eye-tracking model it contains calibrates itself by allowing web visitors to interact with the web page and train an association between the characteristics of the eye and the positions on the screen. WebGazer.js is written entirely in JavaScript and can be integrated with just a few lines of code into any website that wants to better understand its visitors and change their user experience. WebGazer.js runs entirely in the client browser, so no video data needs to be sent to a server and the user's consent is required to access their webcam.

According to the Brown HCI group homepage, the Brown HCI group holds the copyright under the GPLv3 license[2][3]. Companies have the option[4] to license WebGazer.js under LGPLv3[5], while their rating is less than 10.000.000 USD.

When realizing software that combines new (own) source code parts with GPL parts (and when this software is distributed or distributed), the source code must be made available to the users (under the same license conditions: GPL). This is not the case with the MIRA framework, since MIRA only calls WebGazer. Furthermore, the GNU Lesser General Public License (LGPL) was developed to have a weaker copyleft than GPL: LGPL does not require that code parts developed by MIRA (which use LGPL parts but are independent of them: e.g. only library calls) have to be made available under the same license terms. Users and companies may charge money for the distribution of GPL-licensed works (commercial distribution), or distribute them for free. This distinguishes GPL from software licenses that prohibit commercial distribution. The Free Software Foundation (FSF) declares that freedom-respecting software must not restrict commercial and industrial use and distribution (including resale): The GPL explicitly states that GPL works (e.g. Free Software) can be sold or resold at any price[6].

MIRA is essentially an advanced research demonstrator that has already been successfully used in field tests with users in the target group. The eye-tracking routine "WebGazer" contained in MIRA is to be replaced in a future R&D project by an in-house development of a webcam-based eye-tracking technology.

3.9 Technology Readiness Level (TRL)

In the European research context, the Technology Readiness Level is used as a basis and for the evaluation of research projects in the research programme Horizon 2020[7] and in general for the evaluation of future technologies up to full commercial implementation. Where a topic description refers to a TRL, the following definitions apply unless otherwise stated:

- TRL 1: observation and description of the operating principle (8-15 years)
- TRL 2: Description of the application of a technology
- TRL 3: Demonstration of the functionality of a technology (5-13 years)
- TRL 4: Experimental set-up in the laboratory
- TRL 5: Test setup in operational environment
- TRL 6: Prototype in operational environment
- TRL 7: prototype in use (1-5 years)
- TRL 8: Qualified system with proof of functional capability in the area of application
- TRL 9: Qualified system with proof of successful use

[2] https://de.wikipedia.org/wiki/GNU_General_Public_License

[3] https://www.gnu.org/licenses/quick-guide-gplv3.de.html

[4] https://github.com/brownhci/WebGazer

[5] https://de.wikipedia.org/wiki/GNU_Lesser_General_Public_License

[6] GPL FAQ: Sell copies of the program for money, Distribute commercially

[7] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

In this context, the following assignments of TRLs with regard to the overall installation and components in MIRA, in Table 3.

Table 3. TRLs (Technology Readiness Level) following the H2020 EU definition, for total installation and components in MIRA.

Component	TRL	Comment
MIRA (total)	TRL-6	Prototype in operational environment, tested with dementia patients in at least 1 field study.
Routine calibration	TRL-6	Prototype in operational environment, tested with dementia patients in at least 1 field study
Serious Game (Unity)	TRL-6	Prototype in operational environment, tested with dementia patients in at least 1 field study
Analysis of eye-tracking data	TRL-7	Components tested in several field studies (AktivDaheim, PLAYTIME, multimodal).
WebGazer	TRL-7	External component, tested in several installations.

4 Conclusions

From the development of the field-proven MIRA research prototype, we conclude that characteristics of eye movements can be successfully evaluated to provide indicators for Alzheimer's diagnosis.

Future work will involve a larger number of participants in field trials to obtain more robust and statistically significant estimates for the Alzheimer classification.

In addition, several eye movement characteristics will be used for estimation and classification. Furthermore, multimodal acquisition should even lead to better estimates, for example by including features from motion studies as planned beyond the PLAYTIME project.

5 Tables

6 Figures

7 Abbreviations

Table 4. Abbreviations.

Abbreviation	Description
MIRA	Mobile Instrumental Review of Attention
MMSE	Minimental state exam

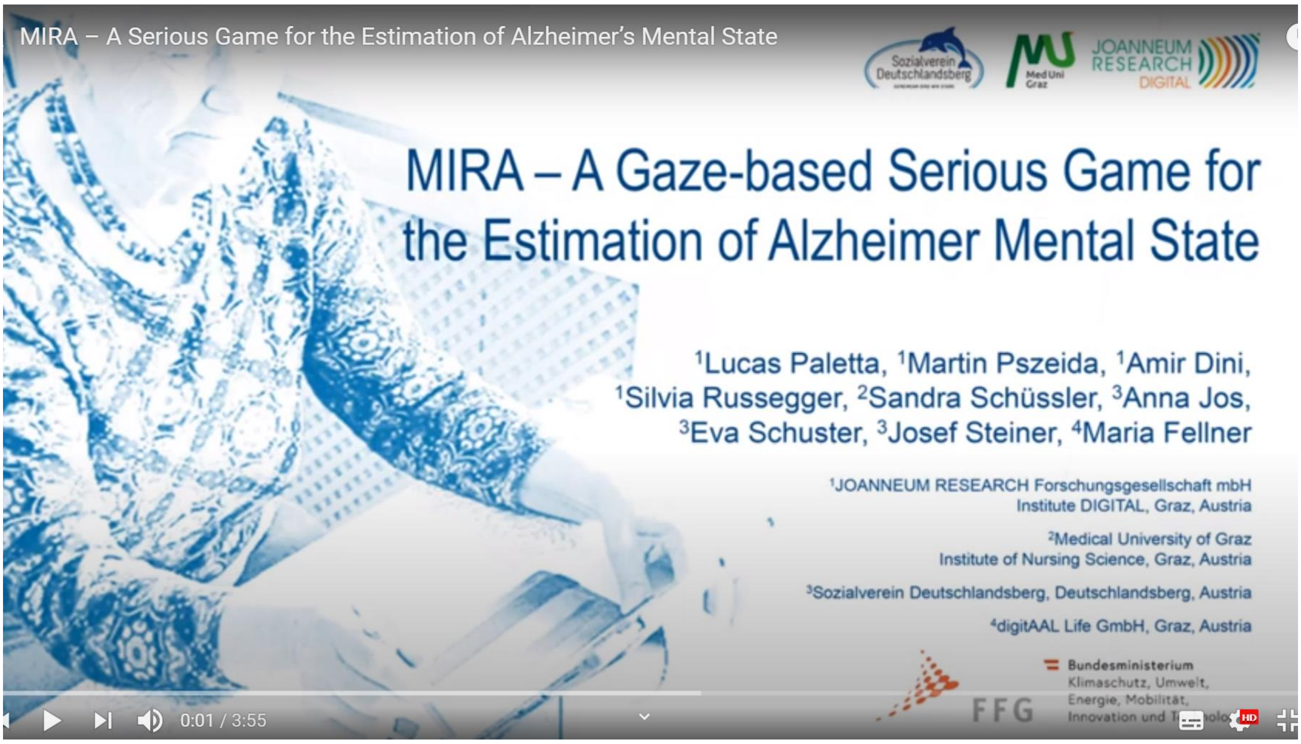
8 Scientific Dissemination

For more information see the scientific article published at the 12th ACM Symposium on Eye Tracking Research and Applications (ETRA2020):

- Paletta, L., Pszeida, M., Dini, A., Russegger, S., Schüssler, S., Jos, A., Schuster, E., Steiner, J., Fellner, M. (2020). MIRA – A Gaze-based Serious Game for Continuous Estimation of Alzheimer's Mental State. *Proceedings of 12th ACM Symposium on Eye Tracking Research and Applications*, *ETRA 2020,* Stuttgart, Germany, June 2-5, 2020, ACM Press.

The paper is attached to this Deliverable.

A youtube video describes in detail the application and the scientific background of the MIRA implementation.



MIRA – A Gaze-based Serious Game for Continuous Estimation of Alzheimer's Mental State

Lucas Paletta
JOANNEUM RESEARCH FgesmbH, Graz, Austria
lucas.paletta@joanneum.at

Martin Pszeida
JOANNEUM RESEARCH FgesmbH, Graz, Austria
martin.pszeida@joanneum.at

Amir Dini
JOANNEUM RESEARCH FgesmbH, Graz, Austria
amir.dini@joanneum.at

Silvia Russegger
JOANNEUM RESEARCH FgesmbH, Graz, Austria
silvia.russegger@joanneum.at

Sandra Schüssler
Inst. of Nursing Science, Medical University of Graz, Graz, Austria
sandra.schuessler@medunigraz.at

Anna Jos
Sozialverein Deutschlandsberg, Deutschlandsberg, Austria
a.jos@sozialverein-deutschlandsberg.at

Eva Schuster
Sozialverein Deutschlandsberg, Deutschlandsberg, Austria
e.schuster@sozialverein-deutschlandsberg.at

Josef Steiner
Sozialverein Deutschlandsberg, Deutschlandsberg, Austria
josef_steiner@gmx.at

Maria Fellner
digitAAL Life GmbH, Graz, Austria
maria.fellner@digitaal.life

ABSTRACT

Persons with Alzheimer's disease demonstrate a dysfunctionality in the continuous tracking of stimuli and are characterized with a significant impairment of their inhibitory functionality of eye movements. In previous work several methodologies of attention analytics were developed with laboratory based eye tracking technology but there is still a lack in providing opportunity for pervasive and continuous tracking of mental state for people still living at home. This work proposes a playful cognitive assessment method based on the antisaccade task. The performance scores of the serious game were analyzed in a field trial with 15 participants being diagnosed with light degree of Alzheimer's disease within a period of 10 weeks. The results present a statistically significant correlation between the game outcome scores and the Montreal Cognitive Assessment (MoCA) score, the golden standard for the analysis of executive functions in early Alzheimer's disease. This indicates first successful steps towards the daily use of serious games for pervasive assessment of Alzheimer's mental state.

CCS CONCEPTS

• **HCI design and evaluation methods**; • **Human-machine interaction**;

KEYWORDS

Eye tracking, dementia care, playful decision support

ETRA '20 Adjunct, June 2–5, 2020, Stuttgart, Germany

ACM ISBN 978-1-4503-7135-3/20/06.
https://doi.org/10.1145/3379157.3391989

ACM Reference Format:
Lucas Paletta, Martin Pszeida, Amir Dini, Silvia Russegger, Sandra Schüssler, Anna Jos, Eva Schuster, Josef Steiner, and Maria Fellner. 2020. MIRA – A Gaze-based Serious Game for Continuous Estimation of Alzheimer's Mental State. In *Symposium on Eye Tracking Research and Applications (ETRA '20 Adjunct), June 2–5, 2020, Stuttgart, Germany*. ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3379157.3391989

1 INTRODUCTION

Dementia is a broad category of neurocognitive disorders that cause a long-term decrease in the ability to think and remember that is great enough to affect a person's daily functioning. Adequate, sufficient and economically feasible care is currently one of the greatest technological and social challenges [Schüssler et al. 2016] and currently there is no cure for dementia [Burns and Iliffe 2009]. A key problem in developing knowledge about dementia and its impacting factors is the lack of data about the mental processes and the psychophysiological dependencies as they evolve over time.

Recently numerous methodologies of attention analytics were developed with laboratory based eye tracking technology but there is still a lack in providing opportunity for pervasive and continuous tracking of mental state for people living at home or in nursing homes in order to detect rapid cognitive decline which might occur within months or even weeks. One possible solution is video-based rapid assessment of cognitive impairment by eye tracking that has recently been introduced [Oyama et al. 2019].

The presented work stresses the importance of continuous assessment empowered by playful interaction within the game component MIRA (Mobile Instrumental Review of Attention). It represents a playful version of the antisaccade task [Crawford et al. 2005] using a device-embedded camera for eye tracking which enables to capture and analyze eye movements during game play. The antisaccade task is known to detect impulse control problems as they occur in executive function related neurodegenerative diseases [Crawford et al. 2005].

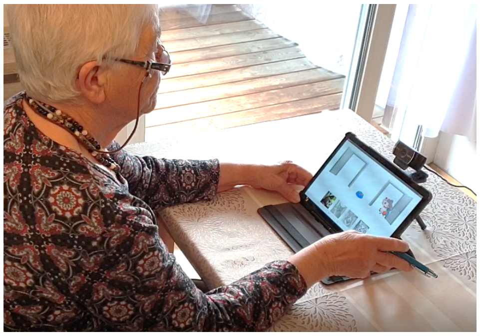


Figure 1: A person with Alzheimer's disease plays MIRA, a serious game version of the antisaccade task [Crawford et al. 2005]

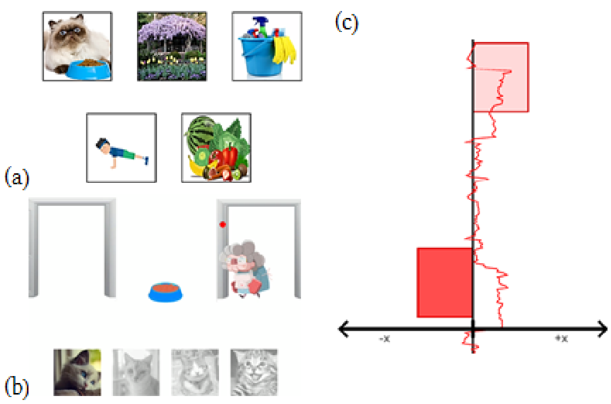


Figure 2: (a) Dashboard of MIRA game suite. (b) Playing the game (red gaze point), (c) gaze track with pro- and antisaccade events.

The results from a field trial with 15 participants diagnosed with Alzheimer's disease demonstrate that participants enjoyed playing over the time period of 10 weeks. The game score shows strong correlation with cognitive assessment scales and demonstrates the potential of gaze-based serious games for continuous estimation of Alzheimer's dementia mental state and decision support.

2 RELATED WORK

Progressive neurological diseases like the Alzheimer's disease are known for the decrease in eye movement behavior [Kuskowski 1988]. [Crawford et al. 2005] has identified by antisaccade tests that Alzheimer patients are characterized by a significant impairment of inhibitory functionality of eye movements. The antisaccade task requires from the test person a voluntary turning away from an actual stimulus and analyzes eye movement behavior further [Kaufmann et al. 2010; [Wilcockson et al. 2019]].

Our approach to the evaluation of the antisaccade test applies a pervasive measurement paradigm [Paletta et al. 2019]. Persons with dementia (PwD) are performing the serious game units at home, not in a laboratory. In the first implementation stage using an external mobile eye tracking equipment (USB-connected Tobii EyeX) the antisaccade test error was characterized by a correlation with the Clock Drawing Test [Critchley 1954]. At that stage, the test did not yet provide a serious game experience and the correlation with mental state examinations was moderate.

3 PLAYFUL ANTISACCADE EVALUATION

Our present serious game for playful antisaccade performance is outlined in the MIRA (Mobile Instrumental Review of Attention) framework, a toolbox of attention-based games for the evaluation of executive functions, such as, the inhibitory functionality of eye movements. The antisaccade test in MIRA is played on a Tablet PC and eye tracking is applied by means of its device-embedded camera[1] using the WebGazer.js[2] software. MIRA starts with a calibration procedure for eye tracking including an adaptation of WebGazer.js by offering the PwD flowers on the screen; each flower has to be fixated and touched by pen or index finger.

MIRA offers a set of game units (1Figure 2), each is related to an important daily activity, such as, feeding pets, gardening, cleaning or cooking. The antisaccade game offers two areas-of-interest (Figure 2), i.e., 'doors' where positive (grandmother) or negative (robber) characters suddenly appear using a randomized selection policy. Upon fixation of the character it becomes 'active', therefore users should fixate good characters (to feed the cat) but avoid gazing at negative ones (who steal the food). Stimulus avoidance (fixation) by gaze represents a typical anti-(pro-)saccade test scheme. Figure 2 depicts a temporal sequence of horizontal gaze amplitudes on display with indications of (correctly/not correctly) gazed (light/bold marked) antisaccades (red blocks). The first character (top) was accidentally fixated but the second (bottom) successfully avoided by antisaccade gaze. Characters appear 10 times, then the game score is computed from a parametrization of pro- and antisaccade events and finally displayed using star rating.

4 EXPERIMENTAL RESULTS

The WebGazer.js software was applied on a SAMSUNG S4 Tablet PC providing 10 Hz sampling of gaze towards the display of the Tablet PC, after a 24-point calibration procedure. A pilot study was performed with 15 elderly with M=81.7, S=4.6 years of age, 91.7% females, all diagnosed with Alzheimer's disease and mental state MMSE M=25.4, S=3.1, Montreal Cognitive Assessment (MoCA) score M=17.9, S=4.5 and Clinical Dementia Rating (CDR) M=1.0, S=0.7. PwD used MIRA within 10 weeks M=6.2, S=4.1 times, they were introduced and assisted by trainers, some learned to play alone. During M=86.3% of playtime users were frontally centered and gaze was estimated. Table 1 depicts most important correlations between the MIRA outcome measures and dementia rating scores. Applying second order polynomial regression enabled to estimate MoCA scores from MIRA outcome scores with an error of M=2.6, S=1.9 MoCA points.

[1] The external camera in Figure 1 was used for other purposes, such as, facial emotion analysis, the results of which are beyond the scope of the work.
[2] copyright (C) 2019 Brown HCI Group, licensed under GPLv3.

Table 1: Statistically significant correlations (Spearman's Rho) between MIRA outcome measures and dementia rating scores.

MIRA parameter	*dementia rating score*	*Spearman's Rho*
mean MIRA outcome score	**Clinical Dementia Rating** (CDR)	-.695**
	Clock-Drawing Test (CDT)	.607*
	Montreal Cognitive Assessment (MoCA)	.713**
	MoCA-1 **Visuospatial** Executive	.729**
	MoCA-3 **Language**	.711**
	Bristol **Activities of Daily Living Scale** (B-ADL): Drink preparation	-.608*
	Bristol **Activities of Daily Living Scale** (B-ADL): Transferring	-.586*

5 CONCLUSIONS AND FUTURE WORK

This work indicates first successful steps towards daily use of gaze-based games for the assessment of Alzheimer's mental state.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the project PLAYTIME of the AAL Programme of the European Union, by the Austrian BMK/FFG (No. 857334), ZonMW, the VLAIO. Sandra Schüssler contributed with knowledge of cognitive assessment strategies in dementia care.

REFERENCES

Alistair Burns and Steve Iliffe (2009). *BMJ*, 2009; 338 doi: https://doi.org/10.1136/bmj.b75.

Trevor.J. Crawford, T.J., Steve Higham, *et al.* (2005). Inhibitory control of saccadic eye movements and cognitive impairment in Alzheimer's disease. *Biological Psychiatry*, 57, pp. 1052–1060.

Macdonald Critchley (1954). *The Parietal Lobes*. New York, NY: Hafner Publishing Company; 1954, doi: https://doi.org/10.1212/WNL.4.5.402

Liam D. Kaufman, *et al.* (2010). Antisaccades: A probe into the dorsolateral prefrontal cortex in Alzheimer's disease. A critical review, *Journal of Alzheimer's Disease*, 2010.

Michael A. Kuskowski, (1988). Eye movements in progressive cerebral neurological disease, in: *Neuropsychology of Eye Movements*, Hillsdale, N.J., 1988, p. 146-176.

Akane Oyama, Shuko Takeda, Tsuneo Nakajima, Yoichi Takami, Yasushi Takey, Koichi Yamamoto, Ken Sugimoto, Hideo Shimizu, Munehisa Shimamura, Taiichi Katyama, Hiromi Rakugi, Ryuichi Morishita (2019). Novel Methods for Rapid Assessment of Cognitive Impairment Using High-Performance Eye-Tracking Technology. *Nature Scientific Reports,*9, 12932 (2019). https://doi.org/10.1038/s41598-019-49275.

Lucas Paletta, Martin Pszeida, Mariella Panagl (2019). Towards Playful Monitoring of Executive Functions: Deficits in Inhibition Control as Indicator for Cognitive Impairment in First Stages of Alzheimer. In: Lightner N. (eds.) *Advances in Human Factors and Ergonomics in Healthcare and Medical Devices.*AHFE 2018. Advances in Intelligent Systems and Computing, vol. 779, pp. 109-118, Springer, 2019.

Sandra Schüssler, Theo Dassen, Christa Lohrmann (2016). Care dependency and nursing care problems in nursing home residents with and without dementia: a cross-sectional study. *Aging Clin Exp Res* 2016 Oct. 28(5), pp. 973-982.

Thomas D.W. Wilcockson, Diako Mardanbegi, Vaiqiang Xia, Simon Taylor, Pete Sawyer, Hans W. Gellersen, Ira Leroi, Rebecca Killick, Trevor J. Crawford (2019). Abnormalities of saccadic eye movemens in dementia due to Azheimer's disease and mild cognitive impairment, *Aging 2019*, Vol. 11, No.15.