SAR-ACT: A Spatial Augmented Reality Approach to Cognitive Therapy

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Abstract: It is predicted that longevity will keep increasing in the forthcoming centuries. Thus, the elder demographic will grow, and the surge of age-related diseases will become more prevalent. These conditions can affect autonomy and affect the quality of life by reducing cognitive and motor capacities. While medical interventions have been progressing, preventive and restorative therapies remain an essential part of the rehabilitation process. Consequently, there is a high demand for tools that can help enhance the effectiveness of therapy. This work proposes a spatial augmented reality framework for creating card-based serious games for cognitive therapy. The objectives of the project are: to use this technology to facilitate the adaptability and personalization of serious games, to create an engaging tool that helps mitigate frustration in therapy, and to help therapists to keep track of patients' progress to adapt future sessions. Two serious games were developed to test the applicability of the framework. An analysis of the work was made by a specialist that concluded it had accomplished the desired objectives and that it has promising results for future validation in cognitive therapy.

1 INTRODUCTION

Since the middle of the XIX century, longevity around the world has increased at an exceptional rate, evolving from the global average of 29 to 73 years old (in 2019) (Max Roser and Ritchie, 2013). According to United Nations' predictions, life expectancy is going to surpass 100 years by 2300 (United Nations Department of Economic and Social Affairs of the United Nations, 2004). This data gives assurance that the world's health will continue its ascending trend, but also warns us that the population will get considerably older. While it is positive news that people will have longer-lasting lives, it raises a question on how will the quality of these lives be (Robine et al., 2009). Age-related health issues will surge with senescence. These conditions can occur in multiples ways affecting motor and cognitive skills, and if we do not work on trying to improve our approach to them, whether being with lifestyle changes, medically, pharmaceutically and therapeutically, then longer lives will not translate to healthy lives (Jaul and Barron, 2017). The surge of neurodegenerative Alzheimer's or Parkinson's disease and traumatic complications such as strokes cause cognition to decay. They can significantly impair the execution of daily tasks, causing elders to lose autonomy and, consequently, their quality of life (Mioshi et al., 2007).

Cognitive impairments can manifest themselves in various areas such as attention, memory, judgment, decision making, logic and abstract thinking, orientation, and language (Glisky, 2019). When patients manifest symptoms of cognitive decay, it is crucial to diagnose their condition and evaluate their cognitive skills early to counteract the potential evolution of the disease (Albert et al., 2011; Svenningsson et al., 2012). Usually, specialists in areas such as neuropsychology, map a neuropsychological profile by performing examinations to evaluate the patient's cognitive skills (Harvey, 2012; Yi and Belkonen, 2011). Following this assessment, they usually establish an individualized rehabilitation plan (IRP) for cognitive therapy (CT). This data can also help doctors identify the disease and its stage of development, and to prescribe appropriate pharmaceuticals. The IRP should result in a series of restorative and compensatory therapeutic activities that can help the elder rehabilitate functions or delay the development of the disease.

It is well established that therapies should start as early as possible, before the brain loses its plasticity, especially with the progression of neurodegenerative diseases (Choi and Twamley, 2013; Clare et al.,

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2019; Niu et al., 2010). IRPs should include tasks that stimulate the brain in the affected areas and delay cognitive decline. They should propose methods to cope with areas where faculties are limited, promoting strategies for enduring plausible advances of the disease, ensuring patient's autonomy for as long as possible.

Serious Games (SGs) can play the necessary therapeutic roles by providing stimuli that aim at sustaining executive functions, including visual processing, working memory, attention, language, and verbal communication. Board-, card-, and computer-based activities can be designed purposely to attain these therapeutic goals while simultaneously trying to engage the patients through the exploration of game principles (Kueider et al., 2012; Lamb et al., 2018; Peretz et al., 2011; Rocha et al., 2015). Recent works have explored emerging technologies such as virtual, augmented and mixed reality (VR, AR, MR) in this area, intending to bring new tools to the path of CT (Ferreira and Menezes, 2020a; Ferreira and Menezes, 2020b; Gamberini et al., 2009; Grealy et al., 1999; Kirner and Kirner, 2011).

While VR and AR offer great possibilities, the use of head-mounted devices may lead to discomfort and rejection by some people. More ecologic approaches may be achieved with the use of Spatial Augmented Reality (SAR) principles, integrating, in a naturalistic way, computer-generated graphics with the users' own physical space, by the use of video mapping techniques (Bimber and Raskar, 2005). Using it, existing objects can be hidden, highlighted, or have their appearance modified to fulfill the game's objectives.

This work comes inline with the above and proposes a framework to support the development of SAR-based Serious Games for cognitive stimulation.

1.1 Paper Structure

The remainder of this paper is organized as follows: Section 2 presents an overview of the research conducted in more conventional and recent works in the area of SGs for CT; section 3 describes a summary of the process for designing an SG for CT, the challenges and requirements that are taken into account for outlining its development, and illustrates the framework concept, its development and implementation; section 4 demonstrates the SGs built, describes their functioning, and their areas of application. Section 5 comprises an overview of a specialist that corroborates the developed works. A conclusion is made for the potential of the concepts presented through an objective analysis of the framework and respective SGs built, comparing them with current and emerging tools for CT in section 6. In this section, it is also made clear the intention of future work on this platform.

2 SERIOUS GAMES AND COGNITIVE THERAPIES

Cognitive exercises frequently simulate everyday challenges by using various and specific tools (Faria et al., 2016; Kurz et al., 2009). These tools can provide stimuli that help patients to relearn the use of their lost or degrading abilities. As for every learning process, it requires consistent repetitions with slight variations of the same activities (Jeffrey A. Kleim and Jones, 2008). The repetitive nature of the exercises and the slow recovery often lead to frustration and tediousness. Therefore, patients can become unmotivated and unwilling to keep up with therapies.

Unsurprisingly, CT's effectiveness is affected by the patient's capacity to endure his assigned exercises (Choi and Twamley, 2013). The main obstacle in developing tools for CT resides in finding two balances: keeping an acceptable challenge threshold that induces evolution in players performance while not being frustrating enough to demotivate, and using mechanisms in game design to lessen the impact of repetition in therapeutic tasks, keeping the player engaged and entertained (Burke et al., 2009). By maintaining the patient engaged, these tools will help the therapist become free to focus on other aspects, such as assessing performance evolution and planning the subsequent exercises. Through the fulfilment of these objectives, the role of a therapeutic tool is then accomplished, and its application will promote the effectiveness of the IRP.

The design of the SG for CT, for the reasons detailed above, is a crucial stage of development. When idealising a game, the developer should focus on one or more of the cognitive deficits it will address. To ensure development will result in useful tools, a strategy may be to base the project on existing certified tools for the intended therapeutic purpose. Then, new creative outlooks can be added through new technologies while keeping the target at the requirements.

Since the patients' conditions can be varied, their IRPs can be considerably different even for the same diseases. It can be challenging for therapists to find tools that adapt to each specific patient's needs. By taking advantage of modern tools, when designing an SG, one should concentrate on adaptability, customisation, and personalisation (Burke et al., 2009; Faria et al., 2018). The bigger the granularity of the changeable elements of the SG is, the easier it will be to adapt to different IRPs, and the more will it suit each pa-

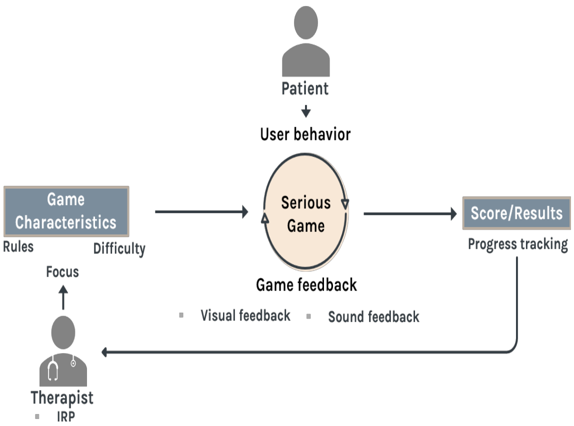


Figure 1: Sgs' iterative cycle.

tient's performance and evolution (Burke et al., 2009; Tong et al., 2014). With specific personalisation of the game, by including components of the patient's life, like personal objects, or recognisable faces or places, one can assure that the player will gain some level of ownership over the therapeutic activities and, this way, achieve higher levels of engagement and motivation (Faria et al., 2018).

The concept of SGs as therapeutic tools also proposes the *gamification* of therapy to achieve better entertainment, engagement, motivation, and a sense of progression. The developer should adopt elements from traditional game principles like score, time, difficulty, and levels. These components can also help adapt the game to the player and translate their performance while doing therapy. For example, the therapist can specify a game, its difficulty level, and other parameters for a patient to play during a therapy session. Afterward, by analysing the attained score and execution time, it is possible to infer about performance and/or recovery. This way, the SG promotes changeable iterations of therapy sessions that will consecutively adapt to the patient's condition.

To keep players captivated while interacting with the game, the interface may provide visual and audio stimulus, but their inclusion must be carefully analysed to make sure they enable the intended goals. Therefore, a cycle of playing, giving feedback, analysing performance, and adapting the game is critical to keep in mind the objectives while establishing the game design, as portrayed in Figure 1. To allow every type of person to use it, the game should be flexible and customisable as much as possible. To this end, it is important to avoid complex control schemes and dynamics that would be hard to tune or adapt by the therapist or caregiver.

3 PROPOSING A SAR-BASED FRAMEWORK FOR CT

From the above, and approaching the available technological solutions for developing tools supporting cognitive therapies, spatial augmented reality appears as an interesting candidate. Contrary to other technologies, in SAR interfaces the user can benefit from a wide field of view, and the interaction with the environment can be made through the handling of physical objects. Since elderly citizens are most likely not used to computer interfaces, SAR can present a valid alternative by replacing accessories like keyboards, computer mice, HMDs, smartphones or tablets with real objects that are more familiar to the user. This particular factor highlighted a great opportunity: to upgrade the use of common therapeutic card games with SAR.

By creating a framework that enables and expedites the creation of projection-based serious games for cognitive therapy for elders, developers can focus on creating engaging, customizable, and adaptive environments to enhance therapy effectiveness. This idea led to the solution proposed in this document, for which the next section presents the concept and identified requirements.

3.1 Concept and Requirements

By using a contemporary outlook at a familiar task, patients can become more captivated in therapy. Considering they are already used to these objects and their manoeuvrability, their adaptation process to the game should be more straightforward. Ideally, by providing stated benefits, both cognitive stimuli and therapy efficiency can be improved.

The interaction of the SAR Cards Framework works in the following way:

1. The user will manipulate cards in the projection area;
2. Cards' locations are tracked by the system;
3. Projections are adapted based on cards' locations and game rules/objectives;
4. Interface provides visual and sound feedback based on player performance;
5. When the session ends, the player score/performance is recorded.

A global overview of the SAR Card framework functionality can be seen in Figure 2.
Given the overall concept of the framework and the design considerations stated in the previous sections, the following requirements were defined for the development of the framework:

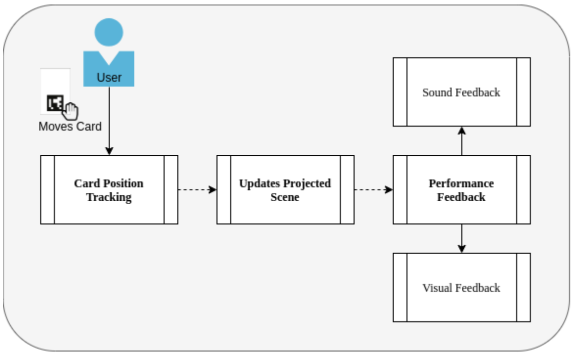


Figure 2: Framework functional overview.

- User manipulation of the cards should be analogous to traditional card games;
- The framework must provide ways to measure user performance in several parameters to encourage self-improvement and for the therapist to analyze;
- Player interactions with the system are made exclusively with cards;
- Inclusion of functionalities to enhance adaption to the player's needs;
- Deliver visual and sound feedback to signal if the user is doing well;
- The system should be flexible and expansible to promote the development of several types of SGs.

3.2 Implementation

The basic elements required to build a SAR system are a camera and a video projector. By inquiring about the logistical aspects of an installation of this kind, it was concluded that it is common for therapy centres and assisted living facilities to already own these devices for other purposes, which facilitates the deployment of the system at reduced cost.
To create the illusion of virtual images registered to physical cards, the following run-time steps are required:

1. Obtain cards' location in the camera's frame (tracking stage);
2. Translate their locations to the projector's frame;
3. Adapt the corresponding images for skewness (mapping stage);
4. Generate a frame of adapted images in their locations;
5. Project over the cards in the area of the game, here defined as the interaction planar surface (IPS).

Firstly, a calibration step is made to retrieve the relationship between three planar surfaces: the camera's frame, the interaction planar surface (IPS) and the projector's frame. This calibration process consists in capturing the projection of a chessboard pattern onto the IPS from the camera's point of view (POV).

It was chosen to use a chessboard pattern due to its regular geometry that allows robust and accurate feature extraction. OpenCV[1] library was used to extract the position of the corners in the camera's and projector's frames, and to establish a correspondence between projector and camera frames. This correspondence is obtained in a compact form as a homography matrix. This relationship also encompasses the relation of both of them with the IPS. A diagram of the projective transformations is presented in Figure 3. With these relations defined, for every point in the physical IPS delimited by the projection area, it is possible to find its approximate projection on both the frames of the projector and camera.

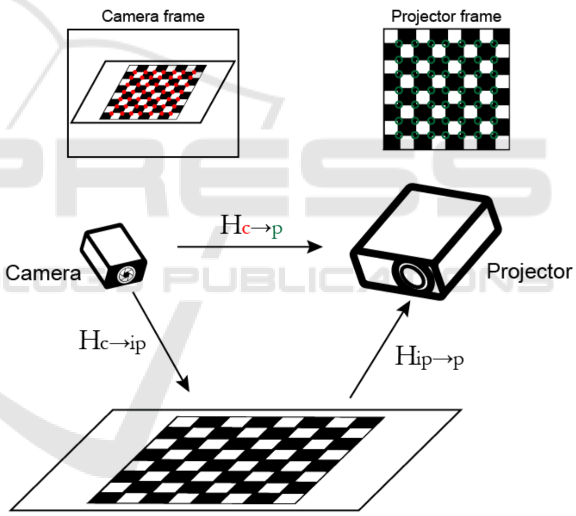


Figure 3: Homographies between planar surfaces.

To track the locations of the cards in the game environment in a quick and flexible manner, each of them received fiducial markers. For the sake of simplicity the fiducial markers choice fell on ARUco (Romero-Ramirez et al., 2018) as their support is readily available. Besides the markers, the cards have a blank area used for the projection of images as described hereafter.

The overall process cycle is as follows:

1. Track cards marker corners positions (X_c, Y_c) in the camera's frame;

[1]https://opencv.org/

2. Transform corners positions to the projector's frame (X_p, Y_p) (using the matrix $H_{c \to p}$ obtained in the calibration stage);
3. Find the perspective transformation between each marker's corners of a flat source image of a card (in pixels) and the correspondent corners in the projector's frame;
4. Warp the image to be projected respecting the found perspective transformation matrix;
5. Add it to the projector's frame in its correct position.

The result will be an overlay image projected onto the cards disposed on the IPS. This enables that the projection be perfectly adapted to any moving card, even if tilted. The projection of the image on a specific card is only stopped if its marker becomes obstructed in the camera view. The setup used to implement the SAR environment can be observed in Figure 4. Figure 5 shows a diagram of the complete processing pipeline.

Figure 4: Setup used to implement SAR SGs.

4 DEVELOPED GAMES

To demonstrate the applicability of the framework, two SGs were implemented. These games were based on established therapeutic tools, and several features were added to cater to patient's needs, while the performance of the player was tracked through the use of game metrics such as score, difficulty and time. The games were integrated into a web platform (composed by a database and a website), to provide therapists with a straightforward way to check on the performance development of each patient's case and decide how to adapt the next therapeutic tasks.

4.1 SAR Cards Memory Game

Memory card-based games are frequently used as a tool for CT (Muragaki et al., 2006). Hence, it was decided to build an enhanced version using SAR.

The patient starts with all the cards facing down on a table (IPS) and has to find all the matching pairs. The player flips cards up one at the time trying to find a pair, if it is a wrong pair, the last two cards have to be flipped down again, if the pair is correct, the cards remain face-up, and the player can proceed to find the next pair. This process is repeated until all the pairs are found. The game is adaptable in the following ways:

- The number of cards is dynamic: the more cards, the harder is the game;
- The images that appear on cards can be completely customised: this allows us to build many types of games. E.g. cards appear with pictures of places, colours, animals, fruits, vegetables, familiar faces, emotions, and the patient has to find matching pairs; cards appear with names of familiars or personal objects, and the players have to find the card with the corresponding image;
- The game also has an option for providing initial help, where the player sees which images are on each card before turning them down.

While the player interacts with the game, the interface provides positive and negative feedback in the form of visuals and sound.

When the game ends (all pairs found), a celebratory screen is shown with the player's score. The score embodies the number of cards (more is better) and time of completion (less is better) used in that session.

The images, the number of cards and help mode should be controlled by the therapist. After finishing a CT session, the scores, time, and number of tries are sent to the web platform for posterior analysis. A demonstration of this SG is showed in Figure 6.

4.2 SAR Cards Pong Game

Pong was one of the first video-games created, and, from an early stage, its application for cognitive rehabilitation was studied. This study helped to introduce the concept of SGs for CT (Lynch, 1982).

The objective of the game is to score goals, throwing the ball through the defence line of the other player while defending our line by bouncing the ball back with the paddle. The game starts with the ball in the middle of the field and goes into a random direction, the ball is reset to this position after a goal. A

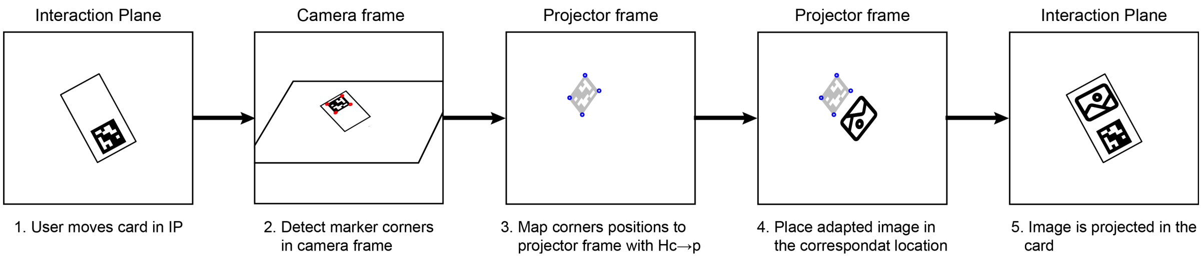


Figure 5: SAR Cards Framework pipeline.

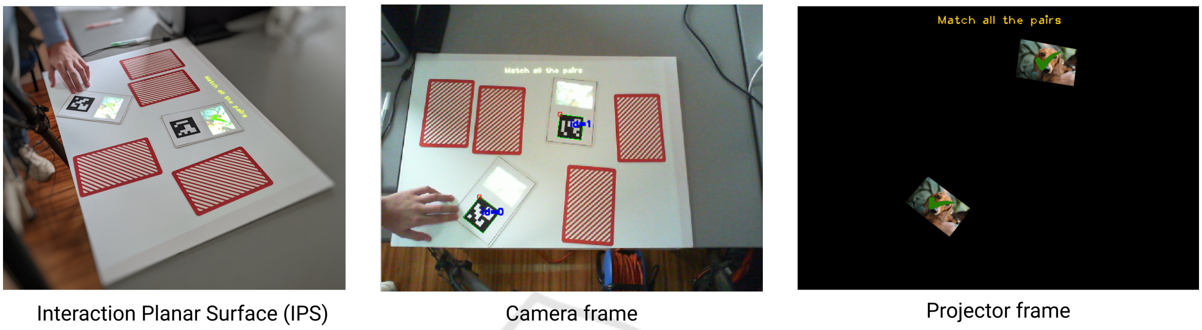


Figure 6: SAR Cards Memory Game demonstration.

SAR implementation of the game was developed using the framework, where the player controls its paddle position by moving the card vertically in the IPS.

The game-play focuses on the attention span, reaction speed and spatial awareness of its patients as it forces the patient to watch, react and predict the trajectory of the ball. The game can be played alone or with another player (being the therapist, caregiver or family member/friend). Multiplayer mode can be an incentive to play since it can be engaging for the patient to be accompanied while doing therapy.

The therapist can set the following adaptation factors:

- Game mode: solo or multiplayer;
- Velocity: the velocity of the ball;
- Bounce dynamics: simple or complex;
- Duration of the game: points or time required to win the match.

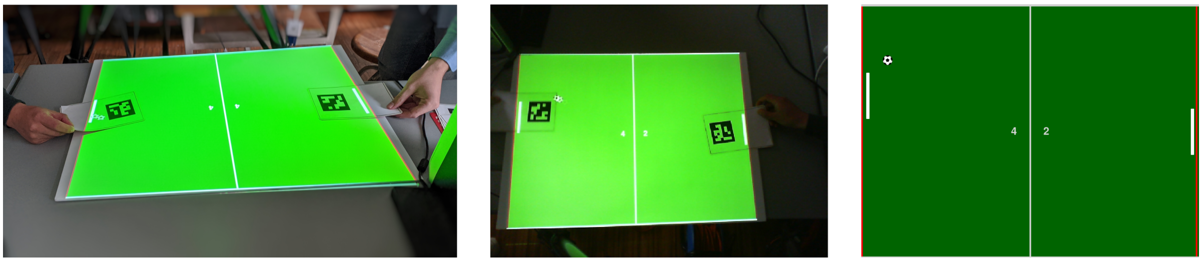
The game provides distinct visual and sound feedback of the bounces in the walls, paddles, when there is a goal and when a match is won. The score, the author of the goal and winner of the match, is presented on the IPS in textual form. At the end of a match, the scores, duration, and number of paddle hits are sent to the platform so they can be analyzed. A demonstration of this SG is showed in Figure 7.

4.3 Patient Performance Interface

The games were integrated into a therapy SG performance analysis web platform. This platform allows us to download the right therapy parameters for the right patient and upload the results of each session. The results are presented with graphs comparing sessions for more accessible analysis (Figure 8).

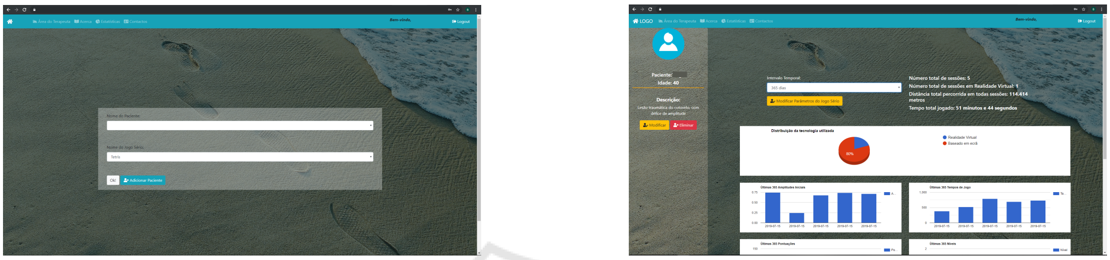
5 ANALYSIS

The design principles, requirements, framework, and the SGs for CT developed were reviewed during and after the development process by a Superior Education Technician. The demonstrated results received positive feedback. The reviewer considered that the objectives set for this work were accomplished from the point of view of the therapist. In her opinion, the SGs created with the framework show promising features that can possibly help in the effectiveness of CT. Thus, there should be made experiments with patients in a real therapeutic environment to test the effectiveness of this SGs. By the specialist's perspective, only with real patient-therapist experience, we will gather information to adapt the SGs to elders' needs.



Interaction Planar Surface (IPS) Camera frame Projector frame

Figure 7: Pong game demonstration.



(a) (b)

Figure 8: Login authentication of therapist (a), and patient performance data (b). Created in (Omitted, 2019).

6 CONCLUSION AND FUTURE WORK

In this paper, we took from the traditional games used to train cognition in CT and added features to enhance adaptability, personalization, engagement and performance tracking. These features were implemented through the use of SAR. This technology requires only a video-projector, a camera, and makes use of the familiar physical space of its user. By only using these components, we highlight the benefits of this type of system when comparing it with more expensive or cumbersome methods like AR or VR. It was developed a framework that makes use of SAR for creating SGs to facilitate cognitive stimulus. The target audience was older adults that suffer from cognitive impairments. Two SGs with different cognition targets were built to test the framework application. The games were analysed by a specialist who gave a positive feedback and reinforced the idea that these games need to be tested with patients in a real-world context. This feedback assures us that our work reveals promising results to create new CT tools. The next step will be to study its impact on a small group of patients to confirm if these benefits translate to more effective therapy. It will also be interesting to study if non-cognitive-deficient elders can benefit from this type of tool.

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