Enhancing Neuropsychological Testing with Gamification and Tangible Interfaces: The Baking Tray Task

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Abstract. Neuropsychological tests are performance-based tasks to evaluate cognitive functions, but often they are particularly long and boring during their execution; these issues can interfere with performance provided by patients or healthy participants. In this paper, we present our gamified and virtually enhanced version of a specific neuropsychological test: The Baking Tray Task (BTT), aimed to assess unilateral spatial neglect (USN), a visuospatial processing disorder. This enhanced BTT version has been developed through STELT (Smart Technologies to Enhance Learning and Teaching) software, a platform which allows implementation of augmented reality systems based on RFID/NFC technology. These materials permit to link together smart technologies and physical materials, uniting the manipulative approach and digitalized technologies.

Keywords: Adaptive learning · Artificial Intelligence · Gamification · Technology enhanced assessment · Unilateral spatial neglect

1 Introduction

Neuropsychological testing and assessment consists into performance-based assessments of various cognitive skills. Normally, neuropsychological assessment is performed with a battery approach, implicating tests of different cognitive skills, with several proofs for each considered skill. This procedure provides assessment of abilities such as memory, attention, reasoning, judgment, problem-solving, visuospatial, and language functions. The battery of tests can be standardized or targeted to the individual participant in the assessment. Successively, the tests scoring may be collected either directly by a neuropsychologist, a psychologist or by a trained examiner.

Neuropsychological tests are intrinsically performance-based. They are structured to require individuals to exercise their skills in the presence of an examiner/observer. Other important information are registered by self-reports of functioning, as well as observations of behavior during testing; these tests have been

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validated for the administration of reliable tests able to pinpoint a potential deficit involving a specific cognitive ability, or to discriminate among impairments in different cognitive domains. However, neuropsychological evaluation can also provide information concerning normal brain functioning and allows monitoring the cognitive status of an individual, especially during older age. Tests are helpful also to determine possible changes in cognition.

The majority of neuropsychological tests are carried out in traditional paper-and-pencil way that requires a long time administration and for this reason this kind of tests are time-consuming for examiners and participants; another disadvantage of traditional tests is that they are tiresome for many participants and patients, who, sometimes, don't complete o perform incorrectly the assessment for tiredness [2]. These problems could be overcome with digitalization and gamification of tests, an approach that will be described in the next sections.

1.1 Gamification of Neuropsychological Tests

Gamification consists in assigning game characteristics to a non-game situation [12] or in implementing design concepts from games, in order to keep involved participants [36]. Gamification also presupposes the concept of flow, represented by the fact that the person who performs the gamified activity is completely absorbed and immersed in it.

In general, each process using games and game-like phenomena in non-leisure settings can be linked with Gamification [22]. A wide variety of contexts has experimented Gamification, including tests. Psychologist, for example, has adopted some gamified tests, utilizing game features in the real assessment situation. The common phrase '*Imagine of*' is easy to find in some tests and participants, unconsciously, accept to play imaging themselves in a fictional dimension to perform task. Also in the field of Education, some learning tools are structured in reference to gamification strategies. In this regard, a large contribution has come from Serious Games [24] applied to assessment [11]: in this case the assessing situation is completely translated in a game. Serious Game have the advantage to be easily carried out on laptop or other electronic devices, substituting traditional tests assessing cognitive abilities, personality traits etc. [32,34].

An example of Serious Game applied to assessment is provided by the evaluation of cognitive abilities or future work trajectories; they can also be fruitfully used with children, evaluating their skills and their preferences for school-related activities [9,16]. This method gives some remarkable benefits, such as a more accurate data recording process; moreover, individuals performing a Serious Game are more involved in the session itself, due to the greater participation promoted by gamification [30]. Using game mechanics and characteristics to motivate and engage people, participation become more implicit and individuals feel themselves completely involved in the performing activity.

1.2 The Birth of Computer-Based and Digitalized Assessment

Modern and digital technologies have opened new opportunities for neuropsychological testing, allowing new computerized testing tools to be developed and paper-and-pencil testing tools to be translated into new computerized devices. Computerized tests have been used in research since 1970s; this digitalization presents some issues, mainly linked to the fact that, although many different test batteries have been developed and new batteries are introduced every year for clinical screening, there are not sufficient normative data and standardized psychometric measures. Conversely, paper and pencil tests are widely approved and adopted due to their high validity and reliability. Paper-and-pencil neuropsychological tests require the presence of a neuropsychologist, essential for the assessment of cognitive abilities, especially for the administration, evaluation and interpretation of scores. One of the important advantages of the conventional paper and pencil neuropsychological tests is their ecological validity (that is the degree to which test performance corresponds to real-world performance).

Despite these numerous advantages, traditional paper and pencil tools show some limitations, for instance, the most commonly administered tests usually do not provide alternative administration forms, this implicates the impossibility to repeat testing over short intervals. Other specific limitations concern the intrinsic nature of tests (time-consuming procedures) including the greater costs, the impossibility to provide accurate reaction times, potential bias related to different examiners etc. All of these limitations could be overcome by a digitalized assessment, on condition that efficacies and ecological measurements are respected. About these issues, the American Psychological Association [1] has recognized the importance of computerized psychological testing and has suggested how to implement and interpret computerized test results in its guidelines.

Furthermore, computerized assessment of cognitive functions can be self administered and can have a shorter duration (e.g., by reducing dead times in stimuli presentation). They may have great validity and reliability due to their great objectivity, precision, and standardization. Computerized performance can also minimize the so called floor and ceiling effects, occurring when differences among participant performance are not fully captured; thus, they can provide more standardized measures of subject performance, crucial for an accurate and early detection of specific pathological disease (e.g., dementia).

It appears clearly that computerized testing will represent an essential part of the clinical setting in the nearest future, above all, in screening procedures, providing an automatized diagnosis, on condition that these new instruments and their results are governed by experts. Feasible, efficacious, and ecological computerized testing could be carried out also at home, with patients and their caregivers, without the specialized clinician support. This is not a no-issue translation: one of the issue represented by automatic assessment could be the fact that clinical sensitivity, allowing neuropsychologists to capture potential shades in a specific domain and to trace a specific cognitive profile, may result difficult to be translated in a computer-based assessment.

In recent times, several tests have been used in clinical field with new technologies support, adopting digitalized and computer enhanced assessment tools. Neuropsychology is the main subject that takes advantage of computer bases diagnostics, as showed by instruments such as Cantab, NeuroTrax and Cabpad. *Cantab* (Cambridge Neuropsychological Test Automated Battery) [28] is focused on three cognitive domains: attention, visuospatial memory and working memory/planning skills. Two main characteristics regarding Cantab are that the battery is quite independent of verbal instruction and responses are provided by touch screen; moreover, is one of the most used computerized battery.

NeuroTrax [14] is designed to assess brain wellness across an array of several cognitive domains: memory, executive function, visual spatial perception, verbal function, attention, information processing speed, and motor skills. In particular, with NeuroTrax it is possible to detect the presence of *Mild Cognitive Impairment* in elderly people. Several tasks are reported as a digitalized version of *old-fashioned* paper and pencil tests. One of the advantages of this software regards some psychometric properties like the accuracy of reaction times.

CABPad (Cognitive Assessment at Bedside for iPad) [35] is a digitalized neuropsychological test battery for bedside screening for cognitive dysfunctions after stroke, in particular the software has the purpose to measure the most common and significant neuropsychological symptoms caused by stroke. The battery is aimed to assess several disorders: anosognosia, aphasia, spatial neglect, depression, episodic memory, attention span, working memory, mental speed, manual motor speed, and executive function (response inhibition). This specific suite adopts a digital version of *Baking Tray Task* (BTT), a particular test that is one of the main interests of the present work and which it will be described later. BTT is a sensitive instrument to assess unilateral neglect, a particular disease be-longing to the group of visuospatial disorders, which will be briefly described in the following section.

2 The Case of Visuospatial Disorders

Visuospatial disorders are, prevalently but not uniquely, caused by posterior right hemispheric lesions and they includes sensory perception disorders, spatial attention disorders, spatial awareness disorders, spatial elaboration disorders, apraxic disorders, sensory ataxia and topographical agnosia.

Humans get information about their body position and other objects through different sensory modalities, keeping in mind, when they move, the starting position of their own body and other surrounding objects. These abilities comprehend the perceptual elaboration of signals coming by senses and the execution of motor actions such as pointing or grasping objects and simple body movements. Sensorimotor information gives internal representation of the body position and other nearby objects. The integration of different sensory signals with information regarding body and objects position permits two type of spatial representation [21] consisting in two principal spatial reference system [26]:

- *Egocentric spatial representations* (also called egocentric frames of reference), with which the position of the objects is codified in relation to the body axis or his parts
- *Allocentric spatial representations* (also called allocentric frames of reference), with which the position of the objects is encoded referring to the location of one object (or its parts) with respect to other objects

Egocentric spatial representations are useful to organize finalized movements such as reaching a target or avoiding an object; conversely allocentric spatial representations are useful to identify objects and to body movements in a space full of objects. Spatial orientation is based on the perception of the surrounding objects from several and mutable prospective, with a strong integration of the two spatial reference systems above described.

2.1 Unilateral Spatial Neglect (USN)

When the ability of analyze and being aware of stimuli and events occurring in a hemispace is compromised and actions towards that part of the space are not possible, we are in presence of the unilateral spatial neglect (USN). USN is usually caused by cortical or subcortical hemispheric lesions and regards the incapacity of elaboration of the part of the space controlateral to the brain lesion [7,10,33].

Nevertheless right USN has been identified following left hemisphere damage (resulting in the neglect of the right hemispace), in the vast majority of cases, the brain lesion responsible of USN is settled in the right brain hemisphere and the neglect regards the left hemispace. Right hemisphere of the brain is usually associated with spatial perception and memory, whereas the left hemisphere is specialized for language plus a compresence of the elaboration of visual information of right side space in both brain hemispheres. Hence the right hemisphere is able to compensate for the loss of left hemisphere function (Fig. 1), but not vice versa [19].

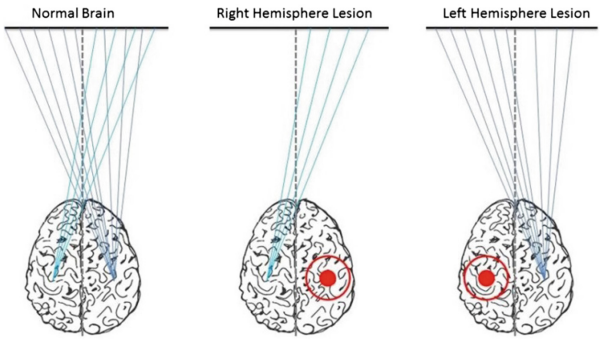

Fig. 1. A model representing the spatial perception processing of the brain

This hemispheric asymmetry supports the hypothesis according to which USN represents a deep cognitive disorder rather a sensorimotor deficits related disorder. Patients suffering of USN can maintain eye direction and head towards the right side of the space and they ignore each stimulus coming from the neglected side; also if the doctors, located in the left side of the room, ask them questions, they can search the origin of the voice in the right side.

These patients, in case of right-brain damage, can also sometimes experiment confabulation about the neglected part of images presented in their peripersonal space, or believe to be in another place [3]. Sometimes they can also avoid having food in the left side of the plate and can ignore also the left side of their own body (experiencing difficulty in dressing and in the care of their personal hygiene) and this compromises seriously the daily-life routine of these people. In neuropsychological field, there are several test adopted by clinicians to diagnose and assess USN and some of them are described in the next paragraph.

2.2 Tools and Instruments Assessing USN

There are many tests adopted by clinicians to assess USN, and different reviews [8,23] describes deeply several USN assessment tool. For example the *Comb and Razor Test* [6] and the *Semi-Structured Scale for the Functional Evaluation of Hemi-inattention in Personal Space* [37] are tests adopted to evaluate USN symptoms through the exploration of personal space in functional activities, such as using a comb or applying makeup.

USN can regard also extrapersonal space, and related assessment tools are usually easy to administer by the bedside once the patient is sufficiently alert. For example, the *Line Bisection Test* [29] is a simple administered test through which the patient is asked to found the middle point, tracing a sign on a paper, of a series of 18 horizontal lines.

Another example is provided by the *Single Letter Cancellation Test* [13] requires the individual to found and delete all '*H letter*' presented on a paper among 52 typed letters. Other two widely used tests have been developed by Arthur Benton and colleague: the *Facial Recognition Test* [4] and *Judgment of Line Orientation test* [5]. These tests present some administration difficulties and their methods of administration could beneficiate of a digitalized/computerized version.

In order to detect USN, there are also several tests requiring the patient to draw; however, these tools have to be used with caution because the presence of apraxia, aphasia, motor deficits, and other visual perception deficits can influence the performance.

An example of these type of test is provided by the famous *Draw-A-Man Test* [15] and *Rey Complex Figure Test* [17], well-known assessment drawing task, especially in Psychology, that are reliable in evaluating perceptual organization, visual memory, and visual motor skills post stroke. Finally, another drawing task assessing USN is represented by the *Clock Drawing Test* [20], where the patient has to write numbers clock inside of an empty circle (usually patients with USN draw all numbers on the right side of the circle). All the presented instruments

are validated tools to assess USN but both patients and doctors can benefit from a computer based version of them, as the task described in the next paragraph.

3 The Baking Tray Task (BTT)

Another choice for assessment of USN is represented by the Baking Tray Task (BTT) [31], a recent neglect test, where patients are asked to dispose 16 cubes as neatly as possible over a 75 × 100 cm board with an edge of 3.5 cm height, as if they were buns on a baking tray to put in the oven. The 16 cubes have a dimension of 3.5 cm and they are placed in a box directly in front of the subject. For the administration of BTT there is no time limit and all the cubes have to be disposed. As regards the scoring of the test, each cube is counted with an accuracy position of 0.5 cm. The cut-off score was based on the worst performance of a normal subject. The baking tray task proved to be a quick and yet sensitive test, suitable for screening purposes and longitudinal studies. Despite standard USN tests, such as cancellation and line bisection tests BTT appears to pick up all cases of at least moderately severe neglect, while standard tests missed a few patients [18]. Moreover, BTT seems requiring low-effort attentional resources in contrast to other neglect task like Cancellation Task [27] and it results to be insensitive to practice and set effects.

3.1 E-BTT: A New Technology-Enhanced Version of BTT

We reproduced BTT in a virtual environment by *STELT (Smart Technologies to Enhance Learning and Teaching)* that allows to create prototypes based on a well-known Artificial Intelligence methodology (Agents Based Modelling) and tangible interfaces (usually concrete objects equipped with RFID/NFC sensors) as tools to support user-computer interactions [25]. It mainly consists in three parts/modules: Storyboarding (aimed to create personalized scenarios), Recording (to track users data) and Adaptive Tutoring (that consists in on-time intelligent feedbacks). In particular, in our idea of gamified BTT, the user has to help a cartoon baker in its work, trying to place 16 toy buns on the baking tray (actually, it is a tablet surface detector) as evenly as possible.

The object of the research is mainly to test the possibility to develop a virtual *Enhanced Baking Tray Task* (E-BTT) able to detect USN (like traditional BTT) and to provide a clear diagnosis of cognitive disorders related to visuospatial abilities. The storyboarding consist, mainly in the presentation of personalized scenarios (the cartoon baker, Fig. 2) useful to provide the test instructions to participants. We expect that the E-BTT will have comparable psychometric properties and will be more engaging for patients. Moreover, with the use of augmented reality systems and adaptive tutoring systems, we aim to add at the assessment procedure another module thought with the purpose of starting a training and rehabilitation program for people affected by USN. Finally, we decided to integrate during E-BTT administration an Artificial Vision module, supported by a camera, able to scan and recognize the cubes pattern arranged

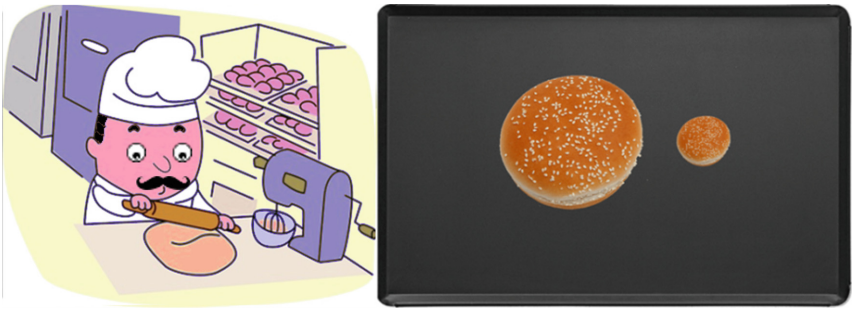

Fig. 2. The starting image of E-BTT: individual is aimed to help Louis (on the left), a famous baker of Paris. The goal is to dispose on the baking tray (on the right), as evenly as possible, 16 small buns, that are a petit version of the traditional one

on the tablet surface simulating the baking tray. In this manner, we aim to reach a clear and accurate performance scoring, and, potentially, it could be recorded also the motor program strategy adopted by subjects in the cubes disposition.

4 Future Directions

The aims of this study will be to evaluate the efficacy of E-BTT adopting not only a computerized modality but also the use of tangible interfaces. More specifically, through STELT software, beyond making the users interaction less boring and tiresome but more participated and involved, we aim to reach an automated diagnosis of performances users, able to retrace the same one made by a clinician, with the advantage to be no more necessary his supervision. It is also important respect the ecological validity criteria of the test, replaying the same reliability of the traditional version in the digital one.

Additionally, STELT enables also the possibility to administrate the task with an adaptive tutoring system, able to give recurring feedback about participants performance and able to adapt test requests on the users specific requirements, keeping trace of their improvements; starting from this point, it would be possible integrate a training and rehabilitation program for patient suffering of USN, enriching the potentialities of the assessment tool.

Once collected E-BTT data, it will be possible include also a learning analytics module; with recorded statistics will be possible deduce more information about the data: the single user performance, the comparison of more sessions in different times, the trend of the whole population etc.

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