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The Assessment of Visuospatial Abilities with Tangible Interfaces and Machine Learning

Antonio Cerrato[1(✉)], Michela Ponticorvo[1], Onofrio Gigliotta[1], Paolo Bartolomeo[3], and Orazio Miglino[1,2]

[1] Department of Humanistic Studies, University of Naples "Federico II", Naples, Italy
antonio.cerrato@unina.it
[2] Institute of Cognitive Sciences and Technologies, National Research Council, Rome, Italy
[3] Inserm U 1127, CNRS UMR 7225, Sorbonne Université, Institut du Cerveau et de la Moelle épinière, Hôpital de la Pitié-Salpêtriére, Paris, France

Abstract. Visuospatial abilities are framed in the capacity of perceiving, acting and reasoning in function of spatial coordinates, permitting to identify visual and spatial relationships among objects. They represent the set of skills conferring individuals the ability to interact with the surrounding world. Whenever spatial cognition is impaired it is important to correctly assess visuospatial abilities. Scientific literature, for this purpose, reports many diagnostic tools that have been adopted by clinicians and neuropsychologists.

In this paper we present a prototype that aims to evaluate the visuospatial abilities that are related to how individuals explore their peripersonal space. In particular, the presented tool makes use of tangible interfaces and augmented reality systems.

In the final part of this study we describe the implementation of an ecological test for the assessment of visuospatial abilities through our prototype by highlighting its advantage in terms of data collection and analysis.

Keywords: Visuospatial abilities · Spatial cognition · Neuropsychological assessment · Machine learning · Unilateral Spatial Neglect

1 Introduction

1.1 The Importance of Visuospatial Abilities

Visuospatial abilities (or spatial abilities) can be defined as the capacity of perceiving, acting and reasoning, as well as operating on mental representations, in function of spatial coordinates. Visuospatial skills permit to identify visual

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and spatial relationships among objects. In particular, they permit to individuate targets in the surrounding space, visually perceive objects, and understand the multidimensional spatial relationships among objects and our environment. These abilities allow us to safely navigate our environment through the accurate judgment of direction and distance. Moreover, these abilities are evaluated in term of the capacity to locate objects, to make global shapes by individuating small components, or to understand the differences and similarities between objects.

Spatial information related to the internal and external reality of an organism comes from all sensory modalities, but the visual system contributes most to spatial cognition of people. According to Mishkin and Ungerleider [24], the brain has two way to process visual information: one is named ventral pathway, located in the occipito-temporal zone, that is responsible for the object identification and recognition; the other way is named dorsal pathway, located in the occipito-parietal zone, that is involved in object localization. In the last years, the difference between these two systems has been revised, for example Goodale and colleagues [19] sustain that both pathways contribute in the same way in the localization and identification of objects, but, while the ventral pathway elaborates visual information to construct a object-to-object (allocentric) spatial representation, the dorsal pathway process visual information in terms of coordinates to make a self-to-object (egocentric) spatial representation (Fig. 1).

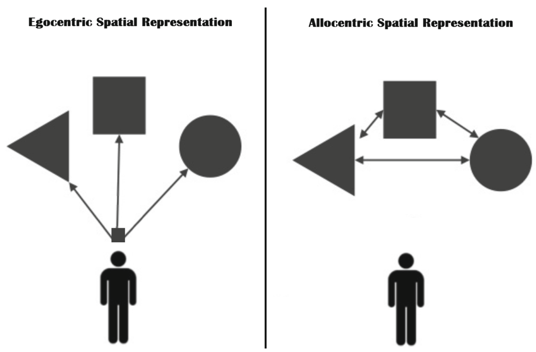

Fig. 1. A model representing egocentric vs allocentric spatial representation

Both pathways consent to act in the external environment and encode information useful to reach and manipulate objects, to recognize familiar places or to get a correct topographical orientation.

Visuospatial abilities are involved in many activities performed in everyday life, so it is important to accurately evaluate and assess them in the context of daily-life routine, in order to identify their impairment that, in certain circumstances, can evolve in a visuospatial disorder.

2 Assessment of Visuospatial Cognition

Visuospatial disorders have been described since the dawn of neuropsychology but they have often received less emphasis than, for example, language disorders. While a language or memory impairment implies an alteration in the behavior immediately evident, spatial impairments assume a brunt only when people undertake their usual activities. In fact, the knowledge of the corporeal and extracorporeal spatial coordinates is the prerequisite of every action: reaching or moving objects, conducting any manual activity, navigating in the streets, driving a car and so on.

The assessment of visuospatial abilities is usually part of the neuropsychologists duties. To evaluate visuospatial impairments it is necessary to consider that a definitive conceptualization of the argument is still missing and that a certain variability persists in identifying which are the basic visuospatial abilities and the appropriate tests to assess them.

A common neuropsychological testing approach is to utilize batteries, consisting in a plethora of tests, to evaluate cognitive functions, including spatial skills. Amongst the many test adopted by clinicians to evaluate visuospatial cognition we can list some of the bestknown:

- *Judgment of Line Orientation* [5], a standardized test of visuospatial skills measuring a person's ability to match the angle and orientation of lines in space. It regards the visuospatial perception.
- *Single Letter Cancellation Test* [12], a task that requires to individuate and delete the target letter presented on a paper among 52 typed letters. It is aimed to asses the presence and severity of visual scanning deficits. Moreover, cancellation tasks come in very different forms and have been administered even to artificial agents [17,18,26].
- *TERADIC* [1], a battery for visuospatial abilities (also known as BVA) developed to analyse putative basic skills involved in drawing and to plan and monitor outcomes after rehabilitation of visuospatial disorders. It encompasses eight tasks assessing both simple "perceptual" abilities, such as line length and line orientation judgments and complex "representational" abilities, such as mental rotation.
- *Behavioral Inattention Test (BIT)* [34], a short screening battery of tests to assess the presence and the extent of spatial exploration impairments on a sample of everyday problems faced by patients with visuo-attentional deficits.
- *ReyOsterrieth complex figure test (ROCF)* [25,30], a neuropsychological test based on the reproduction of a complicated drawing, first by copying it freehand (recognition), and then drawing from memory (recall). Many different cognitive abilities are needed for a correct performance, from visuospatial abilities to attention and planning functions; it allows to highlight even the slightest visual-constructive disorders and to investigate the different copying strategies adopted by people.
- *Visual Object and Space Perception (VOSP) Battery* [21], a battery evaluating spatial and object perception, proceeding from the assumption that these

perceptions are functionally independent. The items require simple responses, and each of them focuses on one component of visual perception, minimizing the effect of other cognitive skills.

Despite the massive adoption and the high reliability of the classical neuropsychological tests, it is possible to notice certain problems such as the long time administration (becoming time-consuming for examiners and participants) or the tiredness generated by it for many participants and patients, who, sometimes, do not complete or incorrectly perform the assessment [2].

To overcome some issues represented by traditional assessment tools, 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, and also the American Psychological Association [3] has recognized the importance of computerized psychological testing suggesting how to implement and interpret computerized test results.

In recent times, another choice of assessment is represented by the adoption of digital, augmented and virtual environment to evaluate cognitive and spatial skills, and some successful application are listed by different authors [10,27].

A digitalized evaluation of cognitive functions can present advantages such as a shorter duration (e.g., by reducing downtime in stimuli presentation), great objectivity, precision, and standardization. The computerized assessment can also minimize the so called *floor and ceiling effects*, occurring when differences among participant performance are not fully detected; thus, they can provide more standardized measures of subjects performance, crucial for an accurate and early detection of specific impairments.

It appears clearly that digital assessment will represent an essential part of the clinical setting in the future, specially in screening procedures, providing an automatized score of performances useful for the diagnosis, on condition that these new instruments become supportive for examiners. Given the significance and the increasing use of technology enhanced assessment tools, we proposed a new tool to assess spatial skills and it will be described in the next section.

3 ETAN: The Assessment of Visuospatial Abilities by Means of a Technology Enhanced Platform

In this work we present ETAN, a platform that supports the use of tangible user interfaces ([11,23], physical manipulable object technologically enhanced) to assess and train spatial abilities; the use of *tangibles* in assessment field is not unusual as showed by several research, both for diagnostic and training purposes [14] This prototype is based on a precedent version of a tool designed for the evaluation of visuospatial cognition [6,8].

More specifically, we developed this prototype to investigate visuospatial behaviors of people in their proximal/peripersonal space, that is commonly defined as the space immediately surrounding our bodies [31]. In peripersonal space it is possible to interact immediately and physically with some stimuli present in the external world inasmuch they are inside the limited portion of space around us, reachable by our arms/hands. In this perspective, personal space is what it is covers the entire body surface of a person, peripersonal space refers to the space defining our field of action, and, lastly, the extra-personal space is instead the furthest one and not reachable by the arts (Fig. 2).

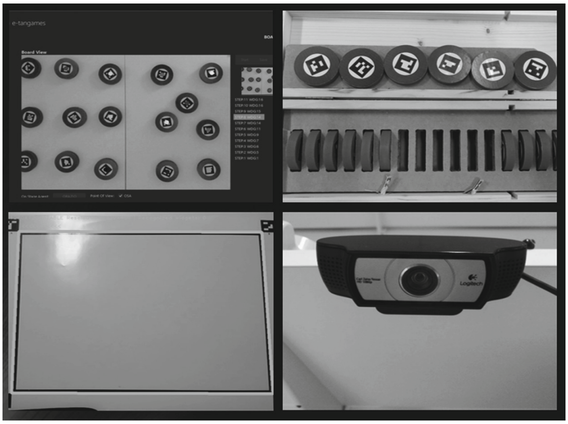

Fig. 2. Materials of the prototype ETAN

The materials of ETAN consist in small disks that are detectable by a camera connected to a PC. It is possible to recreate on the PC the disposition of these objects thanks to a particular kind of tags, popular in augmented reality technology [7] named ArUco Markers [16], that can be traced by a specific software developed with an artificial vision module. Moreover, for each session it is possible to store data about it, both in local that in an online database. The first use of ETAN consisted in the implementation of a well known neuropsychological test: the Baking Tray Task.

3.1 The Baking Tray Task (BTT)

The Baking Tray Task (BTT) represents an ecological test, ideated by Tham e Tegner [32], aimed to assess a specific visuospatial disorder named Unilateral Spatial Neglect (USN), consisting in the inability to analyze and be aware of stimuli and events occurring in half hemispace (usually the left), compromising actions towards that side of the space [33].

During the administration of BTT, subjects are asked to dispose 16 cubes as evenly over a board, *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 front of the subject; over the years, the BTT, while maintaining the initial settings and the way of administration, has been re-proposed in different forms, other materials to be disposed (like small disks) and in both digital and virtual environment [9,13,15].

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, the performance is evaluated clinically counting the cubes in each half of the tray, left and right; left - (minus) right differences greater than 2 are a sign of USN.

The baking tray task proved to be a sensitive test, suitable for screening purposes and longitudinal studies, and as opposed to standard USN tests BTT appears to pick up all cases of at least moderately severe neglect, while standard tests missed a few patients [20]. Moreover, BTT seems requiring low-effort attentional resources in contrast to other neglect task like Cancellation Task [29] and it results to be insensitive to practice and set effects.

3.2 Implementing BTT with ETAN

We decided to implement BTT with ETAN for two main reasons: the first is related to the possibility of obtaining a new kind of data, more informative, based on the spatial coordinates (x, y) of the objects arranged on the surface; the second consists in the fact that with our tool it is possible to carry out a massive data collection and store the performances of the subjects both in the local database and the online one. Moreover, with our platform, it is also possible to track the position of every object. The administration of the task strictly followed the directions proposed by Tham e Tegner, and the only differences with the original task refer to the adoption of disks instead of cubes and the use of a board with smaller dimension (adjustments already proposed by other scientists [4,13]). Upon completion of the task, the platform allows to access individuals' performance on the local database. The data can be easily exported in a CSV file for further analyses.

In this manner it is possible to score the performance not only counting how many objects have been placed in each half of the board but, using the X and Y coordinates, it is possible to develop new statistics to make a more informative diagnostic procedure. One example it will be described in the next paragraph.

3.3 A Machine Learning Approach in Analyzing BTT Data

In the Fig. 3, we can see the spatial arrangements of two participants (c and d) at the traditional baking tray task. Although it is not possible to evaluate these patterns as a sign of neglect, surely they show some sort of cognitive impairment. The problem with the scoring of the traditional BTT is that in this specific case, the two arrangements are not diagnosable as a form of disorder inasmuch the difference of the number of cubes between the left and right side of the board is no greater than 2. At first instance, it would help a measure to discriminate normal arrangements (the ones similar the figure a), from abnormal ones (such as the 3 figures) regardless of whether or not they are signs of USN.

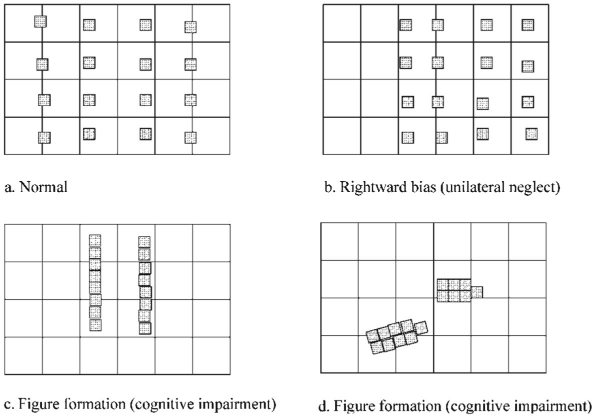

Fig. 3. Example of BTT dispositions (from Appelros and colleagues [2])

Thanks to the X and Y coordinates collected through our prototype it is possible to differentiate the different patterns by using a machine learning technique based on novelty detection approach [22]. Novelty Detection techniques consist of discriminating instances according to whether or not they belong to a given class. This class can be thought of as a concept to be learned. Usually, concept learning involves learning correct classification of a training set containing both positive and negative instances of a concept, followed by a testing phase in which novel examples are classified. In our case, the concept that represents the class that has to be learned is represented by the correct dispositions at the BTT (like the participants a in the Fig. 3).

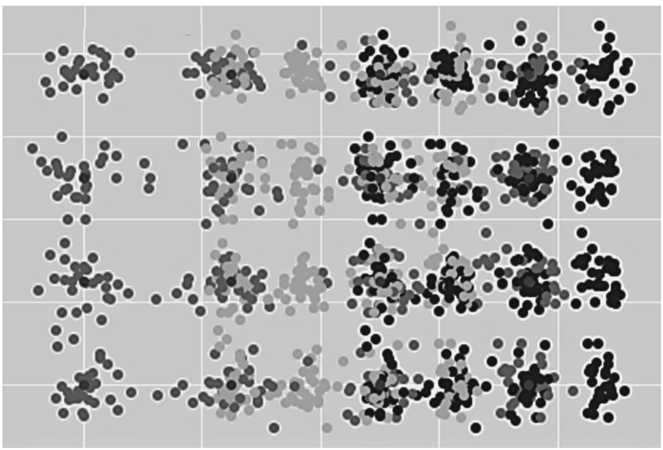

Fig. 4. Simulated BTT dispositions: Normal (medium gray dots), USN (black dots), Other disposition (light gray dots)

In order to test the goodness of the chosen method, we simulated, in terms of X and Y coordinates, three types of dispositions: normal, USN, and dispositions that, while maintaining 8 objects for each side of the board, cannot be assimilated to a proper correct disposition (Fig. 4).

Then, using Sci-kit learn [28], we tested our simulated data with a method from Support vector machines (SVMs) named One-class SVM, that is an unsupervised algorithm that learns a decision function for novelty detection, and is thus able to classify new data as similar or different to a training set. In our case, the application of the ONE-class SVM method proved to be effective in discriminating normal dispositions from the abnormal ones. This means that thanks to our prototype, having more informative data (such as the coordinates) about the BTT, it is also possible to have a more in-depth analysis of the performances, in order to support the diagnostic investigation.

4 Future Directions and Conclusions

The aims of this paper has been to present a new kind of tool designed to assess and evaluate visuospatial abilities. Our prototype ETAN represents an alternative to the traditional tools for assessing peripersonal spatial behaviors, being able to count on the use of tangible interfaces and on the acquisition of previously undetectable data (such as the coordinates of the objects); please notice that BTT is just one possible application of ETAN. The platform, in fact, can be used to implement other forms of visuospatial assessment.

Moreover, ETAN, thanks to its tangible interface, makes the assessment less boring and tiresome for the participants. Additionally, alongside the diagnostic purposes of the use of ETAN, it is also possible to implement a rehabilitative module able to adapt task requests on the users specific requirements, keeping trace of their singular level of abilities; starting from this point, it would be possible integrate a training and rehabilitation program for patients with visuospatial impairments, enriching the potentialities of the assessment tool.

Regarding the technical aspect of the prototype linked to the storage of data, the fact of having available a local and an online database allows us to perform a massive data collection, with which to proceed to an in depth analysis of the data on the spatial skills of the healthy and clinical populations. The adoption of the One-class SVM algorithm described in the previous section represents just one type of possible data analysis to perform; we think that the use of Machine Learning techniques is well suitable for the data that we acquire through our tool, in order to individuate and classify specific alterations of visuospatial abilities.

Once collected data through ETAN, it will be possible develop also a learning analytics module able to track individuals' performances through time and compare them with the rest of the population.

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