A Computational Platform for Visuospatial Assessment

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ABSTRACT

Approaches to visuospatial assessment in neuropsychology remain largely analogue, paper-and-pencil type tests that are far outmoded in the digital era. They are also incongruent with the complexities of cognition and underlying neural systems, and are especially ill-suited to assessing complex disorders of high-level vision such spatial neglect and visual agnosia. There is pressing need for computational methods in neuropsychological assessment. We describe the design and development of a proof-of-concept grid-based, scalable, informatics-driven platform for the dynamic assessment of disorders of spatial processing. Inspired by a problem in behavioral neuroscience, the project involves computer science, computer engineering, and data science.

1. BACKGROUND & INTRODUCTION

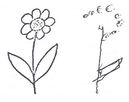
1.1 A Problem in Neuropsychology

- The "visuospatial" functional domain is a major domain of clinical assessment in neuropsychology – and is a complex domain comprised of a hierarchy of cognitive and neural operations. Visuospatial dysfunction is expressed across a range of disorders involving the brain
- Has been for decades assessed using 'paper-and-pencil' tests or computer-administered versions of such tests
- But in cognitive neuroscience, neural systems underlying spatial processing have been described with ever increasing precision
- Neuropsychology has been slow to articulate a comprehensive brain-based model of what it calls "visuospatial function"
- Neuropsychological constructs are often tied to assessment instruments with psychometric roots in the early decades of the 20th century, a practice and legacy incompatible with 21st century brain science

1.2 A Transition to Informatics-Based Assessment Aligned with Brain Science

- A significant development in neuropsychology over the past has been discussion on the need to omics-aligned and informatics-driven neuropsychology (Jagaroo, 2009; Jagaroo & Santangelo, 2016; Bilder, 2010; Bilder et al. 2022; Parsons, 2016)
- The call is for neuropsychology to refine cognitive constructs/operations in neuropsychological assessment -- cognitive operations need to be tied to neural systems
- Computationally defined neurophenotypes can be (a) databased – to create larger data sets – amenable to analytics and machine learning, and (b) more precisely tied to brain imaging data
- In summary: *There is a compelling case to reformat neuropsychological assessment so that is aligned with systems neuroscience and neuroinformatics. To develop a neuropsychological praxis that is scientifically aligned with contemporary brain science, the discipline needs to take the critical step of reinventing its assessment instruments*

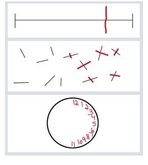
1.3 The Case of Spatial Neglect (aka Hemispatial or Visual Neglect)



What is Spatial Neglect? A neuropsychological disorder, most often occurring after a stroke, in which patients fail to perceived, register, or respond to stimuli on once side of the visual field

Spatial Neglect is not considered to be a result of problems with the primary visual system (i.e., the eyes and their relay circuits to the brain are unaffected and do not produce the condition)

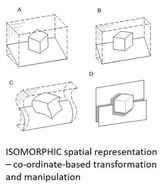
Why is it important to understand Spatial Neglect?
12 – 15 million people worldwide suffer a **stroke** each year and 25% - 40% of this group will experience spatial neglect (Dalmeijer et al., 2015; Esposito et al., 2019)



How has Spatial Neglect been traditional assessed?
Using paper-and-pencil tests – where patients are required to name, draw, copy, or respond to stimuli presented on paper

What are the shortcomings and limitations of this method?
Neglect is a complex and dynamic condition. Conventional assessment methods cannot easily manipulate the stimuli; apply dynamic (e.g. moving) stimuli; and measure gradients of neglect

A Note on the Posterior Parietal Mechanism of Spatial Neglect



ISOMORPHIC spatial representation – co-ordinate-based transformation and manipulation

ISOMORPHIC Representation Matrix of the PPC (theoretical model)

One mechanism of spatial neglect involves Brodmann's area 7, the posterior parietal cortex (PPC). Convergent evidence from neurology and neuroscience suggest Area 7 to be a center of 2D and 3D spatiotopic coordinate representations (Halligan & Marshall, 1994; Halligan et al., 2003; Andersen & Buneo, 2002)

Neuronal cell fields of Area 7 (e.g. 7a, 7b) either code domain specific frames of space (allocentric, egocentric, etc.) or utilize a domain general spatial reference frame and apply it specific contexts (Andersen & He, 2009)

The PPC model of neglect suggests that:
(a) the PPC of the right hemisphere is a center of spatiotopic representation of the entire external spatial field (left and right)

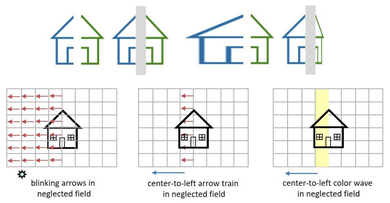
(b) **representational compression** of the left hemifield or part of it, the result of abnormal neural dynamics following a stroke or other brain insult, leads to an extinguishing of a field, manifesting clinically as spatial neglect

(c) certain dynamic/kinetic priming effects, such as synchronized trains of arrows and stroboscopic effects, when presented in the neglected field, can aid perceptual registration of the neglected field or object

This project has been framed through PPC model of neglect, which provides a strong theoretical framework. However, the assessment platform that is the outcome of the project can be applied to neglect no matter what the underlying neural mechanism may be.

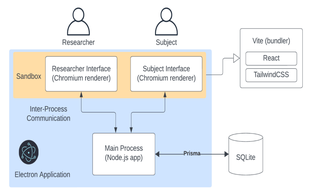
What is the relevance of Spatial Neglect to this Project (why focus on neglect)?

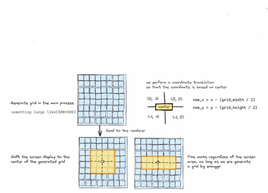
- Perceptual and performance dynamics in neglect provide a convenient model to inform the design of a digitized (computerized), informatics-geared assessment platform
- With a digitized assessment platform, the limitations of analogue assessment can be overcome and a variety of probes can be added to profile the condition
- Digitized data can databased and tracked over sessions and can also be tied to patients' brain imaging data using machine learning algorithms



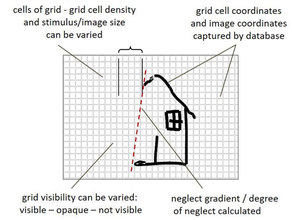
The Research/Development Problem: Neuropsychological assessment has no way of applying the above model from cognitive neuroscience to the clinical (real world) assessment environment. It does not have the tools to do so, and the bridging tools require computer engineering and informatics. The tool required in this case is an informatics-driven, computerized system for the computational assessment of spatial neglect.

Technical Architecture





- The basic mathematics for grid-based mapping involves Manhattan Distance -- applying coordinate translations with 0,0 (center grid cell) as the reference point
- Prisma, the object-relational mapping tool, was used to create the database structure and to apply a migration strategy to a MySQLite file



The system uses a dual-screen computer setup:

- The clinician's (control) screen and the patient's (viewer) screen. Grid information is sent to two renderer processes through Inter Process Communication (IPC) handlers with synchronous communication – for the clinician screen and patient screen renderings
- This allows for the viewing of the same stimulus on the clinician and patient screens while limiting the control parameters/control menu to the clinician's screen

Methods

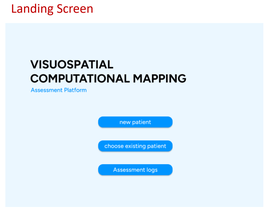
- A technology stack platform was built using *Electron* (open source development framework for cross-platform desktop applications)
- Core design of the platform rests on a grid configuration -- an array of cells of a computer screen
- Cells record the coordinates of content displayed on the grid
- The grid is scalable to different screen sizes – a key feature needed for versatile application of the platform in visuo-perceptual assessment

Results (a functional architecture)

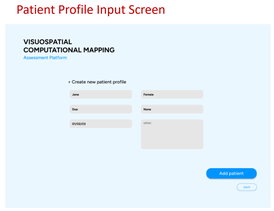
Development of a core software platform (described above) was achieved, with functionality successfully applied to two visuospatial tests used in neuropsychological assessment -- Letter Cancellation and the a few stimuli from the Boston Visuospatial Quantitative Battery (BVQT). The following functions were programmed and tested:

- The clinician selects either the letter cancellation task or an image adapted from the BVT
- Selected test is displayed on the grid matrix. Patient uses a mouse, stylus or touchpad to draw over/trace image (direct copy or recall trials)
- Based on neglect gradient extracted by the software, the clinician can incrementally move the image and have the patient retrace image
- The process is repeated until no neglect is recorded – to quantify line or gradient of neglect
- Grid lines on patient's screen can be shown, made opaque, or hidden

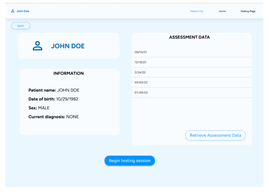
Landing Screen



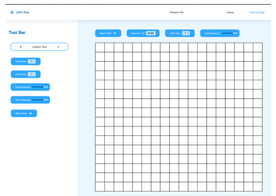
Patient Profile Input Screen



Patient Data (View) Screen



Grid and Test Parameters Selection Screen



Cancellation Test Parameter Selection Screen

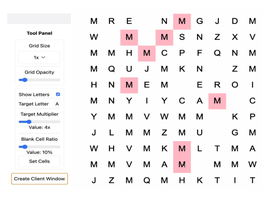


Image Library (BVQT Variants & Other)

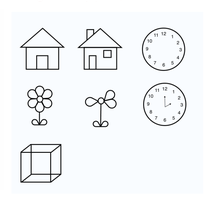


Image on Grid (course grid / opaque gridlines)

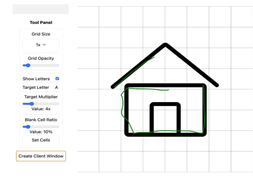
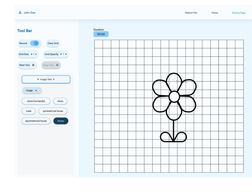


Image on Grid (fine grid / dark gridlines)



Conclusion / Discussion

Over an 8-month development period, a core functional architecture of a computational platform for visuospatial assessment was developed as proof-of-concept. Functionality was tuned to spatial neglect.

With further development, we aim to:

- Create a web-based "freemium" version. This version will be made available to clinicians and researchers. It will not collect patients' personal information but will collect performance data and available information on neurological diagnosis
- With beta version development and datasets, we hope to apply machine learning *Ensemble Methods* – to combine several predictive models and data dimensions (supervised ML) for high quality predictions of patients' visuospatial prognosis.
- Incorporate simple eye-tracking into the platform
- Broaden functionality to visual agnosia

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