Flexible Visualization of Eye Tracking Data to Aid in Assessment of Visuospatial Neglect

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Abstract. Traditional pen-and-paper tests used for assessing visuospatial neglect, a condition which may occur in stroke patients, provide limited amounts of data, often leaving it up to the clinician to fill in the gaps. There is growing interest in applying VR to these situations by adapting pen-and-paper tests for virtual environments. Combined with eye tracking, such systems generate far richer datasets, but also demand new tools to structure and visualize the increased data. This article explores various visualization techniques of eye tracking data through a custom built system, and evaluates its utility with respect to neglect assessment by consulting experts within the field. Overall, the system was deemed highly useful for clinicians. Static visualizations were found useful for quickly identifying patterns and areas of reduced attention by providing an overview of the attention allocation, while dynamic visualizations provide real-time insight into visual behavior, making them useful for investigating the temporal aspects of visuospatial neglect.

Keywords: Visuospatial neglect · Unilateral spatial neglect · Assessment · VR · Virtual Reality · Eye tracking · Visualization.

1 Introduction

Visuospatial neglect is a condition that is highly prevalent after a stroke, and can be generally defined as reduced awareness or attention of visual stimuli at the side of space that is opposite to the side of the brain lesion (the contralesional side) [4]. The condition affects as many as 40% of patients with lesions to their right hemisphere and 20% of patients with lesions to their left hemisphere [16]. Neglect manifests itself in a way where the person ignores parts of their visual field, and can be divided into two main categories: Egocentric and allocentric [4]. Egocentric neglect is when a person fails to attend to the side of space opposite of the brain hemisphere in which the injury occurred, and in the most extreme cases will leave the sufferer to ignore the entirety of (usually) their left side. Allocentric neglect appears differently, where a part (e.g. left side) of every object observed, is ignored. The severity of neglect can vary from mild, which is difficult to detect, to extreme, which is easily identifiable.

Traditionally, neglect assessment has been conducted using pen-and-paper tests, in particular "target cancellation tests" such as the Apples Test or the

Bells Test [15,16]. Here, the patient is presented with a sheet of paper with different figures, also known as stimuli. The objective is for the patient to correctly identify targets among confounders, the latter functionally being visual noise. Missing or incorrectly identifying targets on the opposite side of where the stroke occurred is an indicator of possible neglect. In recent years, there has been an increased interest in utilizing VR and/or eye tracking (ET) for neglect assessment, as this presents a range of opportunities including ecological validity, dynamic tests, access to increased amounts of data with increased accuracy, potential for automated test results, expediting test conduction, as well as detecting subtler forms of neglect [14].

Contemporary eye tracking is predominantly video-oculography, where video from cameras is processed to determine the center of the pupil [2]. From this, a gaze point is calculated, allowing estimation of where a person was looking at a given time [1,5]. As VR has matured and become a more accessible technology, headsets with built-in ET have become widely available. Given that the virtual environment is computed, when factoring in eye tracking data, one can at all times know not only where a person is looking in the virtual environment, but also *what* is being looked at and for how long. This enables creating testing environments that can extract more precise and meaningful data of eye movements.

The eyes are a highly active organ, and their continuous movement is vital for perceiving the world around us [12]. The most frequently studied eye movements can be divided into four categories: fixations, saccades, smooth pursuit, and vestibulo-ocular reflex movements [8]. Fixation is when a person is observing something closely with only tiny movements of the eyes, while saccades are fast, often large, eye movements with the purpose of repositioning the gaze before another fixation occurs. Out of the four categories, saccades and fixations are the ones most prominent in relation to neglect assessment, and are the ones that will be discussed in this article.

Through time, different visualization techniques have been developed to depict the aforementioned eye movements. For example, scanpaths are sequences of alternating fixations and saccades [1], and describes how a person moves their eyes during different tasks, e.g. visual search as during the Apples test. In relation to neglect, there are indications that scanpaths are of particular interest, as someone with neglect may exhibit scanpaths that differs from normative ones [9]. As such, analyzing trajectory plots can be of potential benefit to clinicians during neglect assessment testing. Other relevant techniques include scatterplots, attention maps, timeline visulization, etc. [1].

While a large body of research exists regarding creating and using visualizations of eye tracking data for various purposes [17,13], few previous studies focus on creating and evaluating the usefulness of different visualizations of eye tracking data for aiding the assessment of visuospatial neglect [15]. Still fewer investigated clinicians firsthand to identify their assessment priorities and needs. For example, ET generates large amount of data, so a technique such as scanpath might be informative in some way, but it might also be cognitively demanding to grasp its meaning, rendering its usefulness less than certain in a real world testing scenario. There is therefore a need for more understanding of the perceived usefulness of different visualization techniques from a clinician's point of view.

The objective of this study is to develop a functional prototype with built-in flexibility to generate and display various visualizations of eye tracking data and to evaluate its usefulness in aiding the assessment of visuospatial neglect. Hence, the Research Question to this study is: *To what extent and in what ways are conventional and dynamic in-context visualization methods for visualizing eye tracking data useful in aiding the assessment of visuospatial neglect?*

Based on the definitions of *usefulness* in [11,3], the usefulness with regard to helping to assess visuospatial neglect can therefore be defined as the extent to which users (clinicians) believe visualizations will improve their ability to assess visuospatial neglect in a patient.

2 Related Work

Kortman and Nicholls [9] published a study on the feasibility of using eye tracking glasses to assess unilateral spatial neglect in stroke patients. The participants in the study were given a task of making a hot cup of coffee in a standardized kitchen environment. While they were completing the task, eye tracking data was collected using Tobii glasses. The glasses recorded a video of what the participants were doing, in addition to recording gaze direction and fixations on objects. While analysis of the data was mainly done using statistical tests, gaze plots of the recorded fixations were also created and used. The authors conclude that it is feasible to use eye tracking in combination with real-life tasks to assess and detect neglect.

In a preliminary study by Lloren et al. [10], a case report on a 65-year old woman with severe unilateral spatial neglect was presented. She participated in an experimental eye tracking study where she looked at an image of a washbasin for 1 minute. During this time, eye tracking data was recorded. Using this data, heat map visualizations of fixations were generated and compared to visualizations from a healthy person. The authors conclude that the visualizations of the fixations could be useful for the assessment of neglect as complementary data.

A study by Rossa et al. [14] presents a web application for unilateral spatial neglect called READAPT, which is a computerized adaptation of the traditional Bells Test. For the experimental set-up, the application was used in combination with the Eye Tribe eye tracker to record eye tracking data. The data was used to create heat map visualizations and gaze trajectory animations, which can then be used to analyze the patients gaze. 4 patients and 8 control subjects were used to demonstrate the feasibility and the ability of the system to distinguish between normal and neglect subjects, based on reaction times and target omissions.

Knobel et. al. [7] published a pilot study where a visual search task for head mounted displays was developed and evaluated. The task was a virtual cancellation task which was displayed inside a VR headset. The goal of the task was to find and touch all target stimuli using a hand-held controller. 15 individuals between the ages of 50 and 84 participated in the study. The results showed a high acceptance rate of the VR system, and a significant difference in performance between participants with neglect and participants without neglect. The study concludes that the results support the virtual test as a tool for detecting neglect, and that VR tasks have the potential to help with the rehabilitation of neglect.

3 The Visualization System: ETviz

A system for visualizing eye tracking data, dubbed ETviz, has been developed with the goal of aiding clinicians during neglect assessment tasks. The initial design collected ideas from the related literature, as well as an interview with a clinician working with neglect patients. As a result, scanpaths (aka. trajectory plots), heatmaps (aka. attention maps or density maps), and scatterplots (aka. gaze density distribution plots), both in static and dynamic forms, constitute the starting point to present the visualizations in-context.

The primary interface of ETviz is divided into two parts, where the left side consists of controls for setting parameters and turning visualizations on and off, while the right show a facsimile of the Apples test from the VR environment (see Fig. 1).

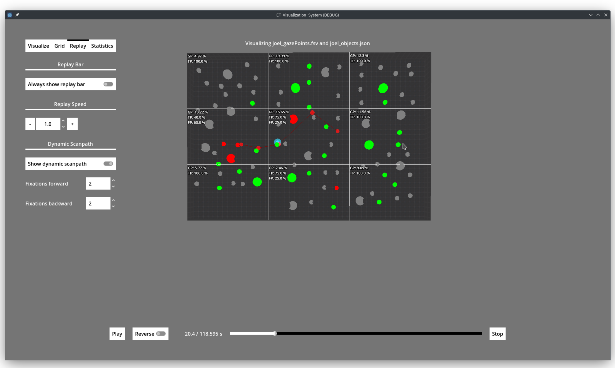

Fig. 1: Screenshot of ETviz during replay of a virtual Apples test. Virtual grid with is enabled, and gazepoint is shown as blue circle. Red/green coloring of stimuli according to correct/incorrect cancellations.

Controls are logically grouped into four tabs, and the different kinds of visualizations are independent of each other, meaning, they can be "layered" where multiple visualizations are shown in the same space at the same time.

Table 1 presents the different kinds of functionality the system, along with its parameters and the resulting visualization output.

Table 1: Functionality overview along with tunable parameters of the ETviz system

Tab	Parameters	Sub-parameters	Parameter type	Output
Visualize				
	Show Test Objects		Binary	Shows/hides the stimuli from the test
	Color Test Ojbect		Binary	Colors the stimuli by cancellations
	Show Scatterplot		Binary	Shows/hides samplings of the eye tracker
	Show Scanpath		Binary	Shows/hides a static scanpath
		I-DT, I-VT	Binary	Event detection algorithm
Grid				
	Show Grid Lines		Binary	Divide the testarea into a virtual grid
		Rows	Integer	Number of virtual rows
		Columns	Integer	Number of virtual columns
	Show Grid Labels		Binary	Shows/hides statistics in each grid cell
	Color Grid		Binary	Colors each grid cell according to TP/FP
	Color Scatterplot		Binary	Color the dots of the scatterplot according to the gaze distribution of the cell they're in
Replay				
	Always Show Replay Bar		Binary	Show the timeline of the test on all tabs
	Replay Bar			
		Play	Binary	Initiates a dynamic visualization of the test progression
		Reverse	Binary	Reverses playback from the current point on the timeline
		Replay Speed	Float	A multiplier which changes the speed of the replay
	Show Dynamic Scanpath		Binary	Show single circle as gaze point during replay of test
		Fixations forward	Integer	Show where the next n fixations/saccades of the replay will occur
		Fixations backward	Integer	Show where the last n fixations/saccades of the replay were
Statistics				
	None			Will show a statistical summary of the test

A prototype VR implementation of the Apples test called Foveal[3] produces data which allows ETviz to create the facsimile of the test and the different visualizations. The input data from Foveal come in two formats: A JSON file which contains data about stimuli, such as position, size, type, whether it was cancelled by the participant, etc. Additionally, a CSV file containing the raw eye tracking data, along with position and rotation of the VR headset and the time (in ms) when the eye tracker conducted the sampling, is produced. Both files are necessary to for ETviz to function. It should be noted that since this study is to assess the usefulness of the visualization system for clinicians, it was deemed unnecessary to collect data from someone with visuospatial neglect. Therefore, data collected for this study has been from one healthy individual during a two minute test run of the virtual Apples test.

ETviz have builds for all major desktop operating systems (Linux, macOS, Windows), as well as Android and the web. It's highly likely that builds can also be produced for iOS, though this hasn't been tested due to lack of hardware. The system was developed using the Godot game engine (version 4.3; also tested on 4.4 and 4.5), due to its remarkable platform support, tiny resource footprint, and open source nature. The programming language of choice is GDScript, and no plugins or extensions to the Godot game engine are needed to run the project.

[3] developed by the team behind this article and the ETviz system

4 Evaluation

The main goal of the evaluation of the system prototype was to examine the usefulness of the visualizations presented in ETViz with regard to aiding the assessment of visuospatial neglect. Both the general usefulness of the system and the usefulness of each individual visualization technique have been evaluated. The latter is conducted to provide fine-grained understanding of if, and how, particular chosen techniques such as scanpath and scatterplot are of help to the task at hand. The evaluation was completed using a semi-structured questionnaire as a data generation method. Three clinicians working directly with neglect patients were recruited and responded to the questionnaire. The experts were given access to a video demonstration that showcases the system prototype[4] and then answered the questionnaire in writing.

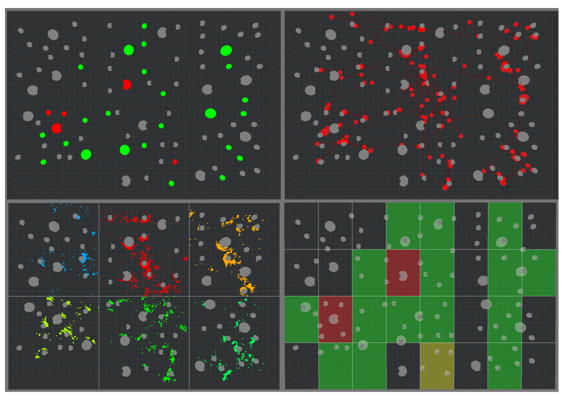

Fig. 2: Examples of different visualizations in ETviz. Note that since visualizations can be layered, a single quadrant may contain multiple different types of visualizations.**Top left**: Stimuli colored according to correct/incorrect cancellations. **Top right**: Static scanpath layered on top of stimuli. **Bottom left**: Layered stimuli, grid, and gaze distribution (colored according to density). **Bottom right**: Stimuli and grid, the latter colored according to correctly/incorrectly cancelled stimuli within the grid cell.

4.1 The Usefulness of the Visualizations

Table 2 presents the results of the usefulness of single visualization techniques. Most of the techniques are deemed useful by the clinicians, but two visualizations stand out, in particular.

- *Grid*: using grid lines to divide the test area and visualizations into a grid can show the areas where a patient might have reduced visual perception and enable performance comparisons across sessions or patients in a standardized manner. Example: Fig. 2, bottom left and right.

[4] available at https://www.youtube.com/watch?v=fpl2cDEL308

- *Color scatterplot*: the ability to color the scatterplot based on the distribution of gaze points in the grid can enhance interpretability by making density patterns immediately visible. Example: Fig. 2, bottom left.

On the other end, two of the visulizations are considered somewhat useful as the usage scenarios seem to be less certain.

- *Scanpath*: the ability to visualize saccades and fixations as a scanpath visualization is considered highly informative, in the meantime, its tends to become cluttered by showing too much at once. Example: Fig. 2, top right.
- *Grid coloring*: the ability to color the grid cells based on whether they contain mostly true positives or mostly false positives seems very promising, but its usefulness in assessment is yet unexplored, and therefore needs more investigation before its true utility is uncovered. For example, patients might have allocentric neglect, egocentric neglect, or a combination of both. How does this affect the coloring of the grids? Does it become random, or does it show something truly useful? Example: Fig. 2, bottom right.

Overall, the judgment of usefulness of individual techniques seem to gravitate around the following aspects: i) Static visualizations show a good overview of large amounts of data ii) Directly measurable indicators are necessary for neglect assessment, iii) Potential additions and improvements not existing in current assessments, such as the temporal aspects of neglect behavior. It also seems that, in addition to the direct usefulness of helping clinicians assess the neglect condition, they put a great deal of emphasis on its usefulness in communicating with patients and their families. This is exemplified in V5 and V7 (see Table 2) where the clinicians specifically mention its usage in a communication setting.

4.2 The Overall Usefulness of the System

In terms of the overall usefulness of ETviz, all experts expressed that they found the system to be of great value. One clinician expressed that "the system appears to be highly useful and well-conceived for aiding in the assessment of visuospatial neglect", and that the system "provides both quantitative and qualitative insights that go beyond traditional paper-and-pencil tests". Another stated that the system itself is highly useful and holds a lot of promise, but can be improved, mainly on the UX side. It was also pointed out that there needs to be balance between flexibility (ample options by tuning the parameters) and standardization (with fewer options and less parameters to tune) to reduce cognitive load in real working sessions.

4.3 Potential Improvements

The participants were also asked for any potential comments or additions regarding making the existing visualizations in the system more useful. Several suggestions are centered around better interface (e.g. choosing a different color for the stimuli) and user experience (such as where to place legends). Some are

Table 2: Overview of usefulness of the visualization techniques

No.	Usefulness	In what way is it useful	Quotes
V1 Scatter plot	Useful	Useful for assessing and getting an overview of where the attention of a patient is allocated	"Allows us to quickly identify asymmetries in gaze distribution" "Useful for getting an overview"
V2 Scanpath	Somewhat useful	For assessing how a patient explores and moves their gaze across their visual field	"Scanpath visualizations are highly informative" "Yes and no. Does tend to become a bit cluttered by showing too much at once."
V3 Color TP/FP	Useful	Helps to visualize the task performance of a patient	"Enables more nuanced error analysis, which can be important in differential diagnosis or monitoring progress over time"
V4 Grid	Highly useful	Show the areas where a patient might have reduced visual perception and help with objective scoring of the assessments.	"Aids in comparing performance across sessions or patients in a standardized manner" "Very, very, good function. One of the most useful. Is vital for the system"
V5 Color scatterplot	Highly useful	For visualizing the distribution of attention	"Enhances interpretability by making density patterns immediately visible" "More intuitive for non-specialist clinicians or when communicating results to patients and families"
V6 Grid coloring	Somewhat useful	For seeing which areas of the test receive more attention, as it adds more information that can be used to assess the condition of a patient	"Allows spatial mapping of performance accuracy and helps pinpoint specific regions where patients may consistently misidentify or miss stimuli" "Like the thought and seems very promising, but does venture into somewhat unknown territory, and therefore needs more exploration before its true utility is uncovered"
V7 Dynamic gazemarker	Useful	Able to visualize the performance and visual exploration of a patient in real-time	"Particularly useful in understanding temporal aspects of neglect behavior" "Can be useful in giving an impression of where the patient has looked." "Also something that can be beneficial by showing to the patient/family member"
V8 Dynamic scanpath	Useful	For understanding how a patient uses their gaze to search and explore visual stimuli.	"Deepens our understanding of visual search behavior" "Helps to tidy up the scanpath, by adding some predictability of where to look. This helps makes things calmer, and helps the clinician watch something that is inherently messy".

more concerned with the additional functionalities should it be developed further as a real product (e.g. exporting and printing functions). Still a few suggestions stand out and warrant further consideration: i)mapping participants in "real time" on top of each other ii) visualizing group data (e.g. averages of patients with stroke to the left hemisphere vs. the right), and iii) comparing against reference data when presenting statistics/visualizations.

5 Discussion and Conclusion

Visualizations of eye tracking data in the context of neglect assessment holds promise and opportunities, and is a relatively young and unexplored area. While visualizing data from eye trackers is not new, such displays tend to converge on three static visualizations: scanpaths, heatmaps, and scatterplots. Their prevalence attest to their usefulness, but at the same time they have their shortcomings. By being static in nature, they suffer from becoming cluttered the more data that is collected, and by extension places a limit for how long the eye tracking sessions can last. Additionally, such visualizations are usually not in-context, providing datapoints on a cartesian plane, but lacking display of stimuli/AOI from the eye tracking session. The different visualizations are also often disparate, making using them conjunctly in a direct manner cumbersome, if at all possible.

Part of the novelty of our approach is providing an interactive solution, incorporating both static and, especially, dynamic visualizations. By providing in-context, static visualizations, we retain the advantage of quickly forming an impression of the degree of neglect a patient might have. And, by keeping all visualizations in the same frame of reference, we also provide opportunity for layering visualizations, which is beneficial for examining events in greater detail, e.g. gaze patterns around correctly cancelled targets vs. incorrectly cancelled ones.

Dynamically visualizing the eye movements have two distinct advantages. Firstly, it contends with the issue of clutter, as not all data from the eye tracking sessions has to be shown at once, effectively removing any constraints pertaining to the length of the eye tracking session. It additionally gives a tool for fine grained examination of temporal aspects, which opens up new possibilities that may be of particular interest for clinical assessment, for example obtaining more insights into how a patient's performance degrades over time, a phenomenon known to happen in people with neglect [6].

Knobel et al. [7] demonstrated that there is high acceptance rate for using VR as tool in neglect assessment, and along with several others have found that the use of eye tracking data can assist in detecting visuospatial neglect [7,9,10,14]. However, there is a lack of studies looking at the subject from a clinician's perspective and addressing the utility of such a system in a clinical test setting where requirements may be different and tend to be more pragmatic in nature. By focusing on not only on the usefulness of different forms of visualization, but also on the usabililty of the system, we provide insights into aspects that should be considered for a product intended for end users (i.e., clinicians).

In this study, we have developed and implemented a flexible visualization system called ETviz to visualize eye tracking data for the purpose of aiding the assessment of visuospatial neglect. The evaluation of the system prototype investigated the usefulness of the visualizations. We contributed to the body of research on eye tracking in neglect assessment with perspectives from clinicians, thus complementing other usability studies. The finding uncovered more fine-grained insights with regard to the different visualizations. However, due to neglect assessment being a highly specialized field, the number of experts giving statements are limited, and further research is needed to ensure reliable and more broadly generalizable results.

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