Plexlines: Tracking Socio-communicative Behaviors Using Timeline Visualizations

John Lee, MS, Ha-Kyung Kong, Sanny Lin, Karrie Karahalios, PhD
University of Illinois Urbana Champaign, Champaign, IL, United States

Abstract

In this paper, we visualize children's coordinated gaze, gesture, and vocalization to better understand communicative behaviors and to identify developmental delay, specifically in the domain of Autism Spectrum Disorders. To date, existing behavioral data from clinical assessment instruments are often stored in raw text files or spreadsheets. This wealth of data is then represented as a single number summarizing behavior. Our approach transforms this data into a graphical story of a child's behavior. To do this, we created Plexlines, a graphical record of a child's social and communicative behavior. When presented with Plexlines, clinicians and researchers formed their own strategies for exploring the visualizations and independently identified children in need of further evaluation. Feedback showed that Plexlines has the potential to be integrated into existing behavioral evaluation processes, aid in the detection of developmental delays in young children, and serve as a visual artifact to better communicate with parents.

Introduction

In cases of Autism Spectrum Disorder (ASD), early intervention—as young as six months old—is critical to successful treatment and can mitigate developmental delays [1]. However ASD is difficult to diagnose early, as there are no easy medical tests to diagnose the disorders, and each patient needs individual attention. Often times social and language delays do not show until children interact with their peers in preschool [2], which is considered a late detection and reduces the effectiveness of treatment [3]. Researchers and clinicians are now turning to quick screeners for early assessment that observe the communicative behavior in young children [4]. However, it is difficult for clinicians to make an accurate behavioral model based on data in its current text-based format. We developed Plexline as a graphical representation of behavioral data for use in understanding communicative behavior and spotting developmental delay in children under 30 months of age

We seek to reveal the hidden layers of human behavior in a visual format, ready for rapid interpretation. Current clinical interfaces include charts and tables, but they do not provide a full picture for making behavioral assessments quickly. Instead of following complicated coding guidelines and instruments to produce a number that represents a level of social engagement, Plexline combines multiple data types to reveal the unique dynamics of a child's behavior that cannot be observed first hand. For our visualizations, we gathered behavioral data from annotations of the Rapid Attention Back and Forth Communication Test (RABC) conducted by our collaborators. The RABC is a structured experimental 5-stage social play protocol (greet, ball, book, hat, and tickle) between a child and an examiner. It was developed jointly by Emory University and the Georgia Institute of Technology for children aged 9-30 months to collect data about a child's social and communicative behavior as a pre-screener for ASD [5].

Using hand-coded annotations, we categorize RABC communicative behaviors into gaze, gesture, and vocalization. The categories are color-coded and each behavioral event is drawn on the timeline as a colored circle. Laying out these circles along a timeline creates an overview of an individual child's behavior. By taking advantage of a common visual language, we reveal complex patterns of coordinated behavior.

Two Plexlines

In this section, we introduce a use case for Plexlines by presenting two contrasting Plexlines from two different children (see Figure 1). A legend for Plexlines can be seen in Figure 1c. In this stage of the RABC, the examiner presents a ball to the child and says, "Look at my ball." Typical reactions to the examiner's statement (also referred to as an examiner bid) include looking at the examiner (blue circle) as they are speaking, and using either gesture (green circle) or speech (red circle) to ask for the ball. Figure 1a shows the Plexline of a child that display this common pattern of behavior. The diameter of the circle is proportional to the duration of the annotated behavior.

There is a variance in the timing and behavior responses in the Plexlines of typical children. However, the Plexlines share a common rhythmic pattern of overlapping circles representing coordinated gaze, gesture, and vocal behaviors. Notice how the Plexline of the second child in Figure 1b compares to that of the first child. Unlike the first Plexline,

the green circles for the gestures are small and there is lack of blue circles representing gaze towards the examiner. When watching the corresponding video for this Plexline, the child appears sociable to an untrained eye. However, the child fixates on the ball and rarely makes eye contact with the examiner. This lack of interest in the examiner is a critical sign of developmental delay [6, 7].

Plexlines allow users to quickly spot outliers in communicative behaviors such as those exhibited by the second child, and capture nuances in behavior that are difficult to spot in person or in video. We will provide more detail on the design of the Plexlines and the tool for manipulating Plexlines later in this paper.

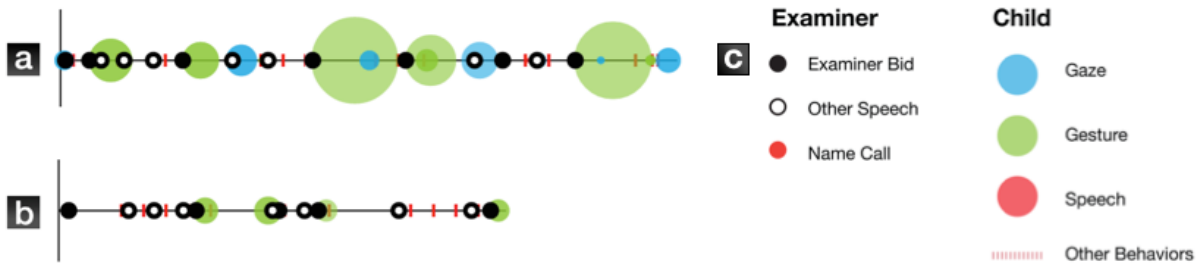

Figure 1. Two Plexlines showing different levels of communicative engagement during the ball stage of the RABC. In (a), the child's gestures (green) are punctuated by gazing at the examiner's face (blue). In (b), the child shows no gaze toward the examiner, a warning sign for developmental delay. (c) is the legend of the annotation categorizations. An Examiner Bid is an attempt by the examiner to initiate a response. The blue gaze circle denotes gaze towards the examiner. The green gesture circle denotes any communicative gesture. The red speech circle denotes vocalization and verbalization. Hatch marks represent other non-directed behaviors.

Related Work

Current work in behavioral visualization is often limited to one aspect of behavior, such as visualization of only speech or only eye gaze (e.g. [8-10]). In addition, there is little application of behavioral visualization in current clinical processes. We tackle the challenge of visualizing multimodal behavior on a temporal graph. In this section, we will discuss our main inspirations from visualization work in healthcare, though this is not an exhaustive list of work in the field.

Prior work in visualization in healthcare focuses on electronic health records. Rind et al. have reported on the extensive literature in information visualization for electronic health records in their recent work [11]. The ongoing work of LifeLines2 [12] and EventFlow [13] have produced powerful tools for visualizing sequences of events, notably for visualizing a patient's treatment history. Hsu et al. built a tool which generates a timeline interface showing the change of medical condition of patients to understand and summarize patients' conditions [14]. Ozturk et al. showed that visualizing a patient's medication history can be helpful, especially in emergency care, and developed an application that converts a patient prescription history data into a simple timeline visualization [15]. Visualization of medical records not only aid doctors in presenting data in an efficient manner, but also in discovering insights. Klimov et al. and Shahar et al. both focused on building an intelligent interactive visualization system which fully utilizes existing domain knowledge to further assist clinicians [16, 17]. Work by Gotz et al. visualized patient data based on similarity to allow human experts to refine and reference comparable patient data [18]. Similarly, Stubbs et al. proposed an interactive system for exploring and visualizing data to identify similar patients from a database [19].

While there is extensive work in visualizing personal medical histories, visualizing behavioral data is underrepresented in this field, especially for diagnosing and pre-screening for ASD. However, more researchers are applying technology for screening and diagnosing ASD to supplement existing procedures. For example, Boraston et al. have utilized eye-tracking to investigate gaze behavior [20], and Hashemi et al. used computer vision to assess visual attention in children [21]. More recently, Han et al. presented a visualization that allows for a comparison of any two behaviors in the RABC dataset that occur at or around the same time across multiple sessions [22]. In our work, we focus on presenting many co-occurring events of a single child in a compact visualization, which allows clinicians and researchers to examine and compare behavioral records of multiple children.

Project Background and Motivation

We focus on techniques for behavioral imaging of social and communicative behaviors and creating graphical visualizations to aid clinicians in making a diagnosis. Currently, researchers and clinicians often collect quantified scores of various behaviors from the behavioral coding stage. Well-known protocols such as the Autism Diagnostic Observation Schedule (ADOS), or the Autism Diagnostic Interview-Revised (ADI-R) result in a single number or binary evaluation representing social communicative engagement with no convenient way to interpret and explore behavior data temporally [23, 24].

In order to create graphical visualizations of child behavior, we have collected data of over 100 children, aged 9 to 30 months, engaged in a five-minute RABC session. The examiner evaluates the child's responses to the explicit social bids and the ease of engaging the child. Specifically, the examiner seeks to elicit social attention, back-and-forth interaction, and social communication from the child. The dyadic nature of the RABC allows us to break interactions down into smaller parts and observe engagement at different levels of granularity. Our collaborators collected the RABC data as part of a NSF Expeditions effort and annotated each RABC video. Three independent coders were trained using RABC sessions to have at least 90 percent overlap for each of the annotations. Then, the coders hand-annotated the videos by categorizing the child's gaze, gesture, and speech for each frame.

Annotation Taxonomy

As a human-centered timeline, Plexlines are styled to focus on the child, with brightly colored circles representing the child's socio-communicative behaviors. We are mainly interested in the child's reactions and responses to the examiner bids. We separate the social behaviors of the child into gaze, gesture, and speech, which are color-coded blue, green, and red, respectively. Because we are primarily interested in behavior directed toward the examiner, only such behaviors are included in the default circle categories. Thus, an annotation labeled gaze at the examiner is visualized as a blue circle, while gaze at the ball is not. However, we still include the annotations of the non-directed behaviors in the visualization for reference. Non-directed behaviors are grouped into an independent category and visualized as hatch marks on the Plexline, regardless of type of behavior (see Figure 2c).

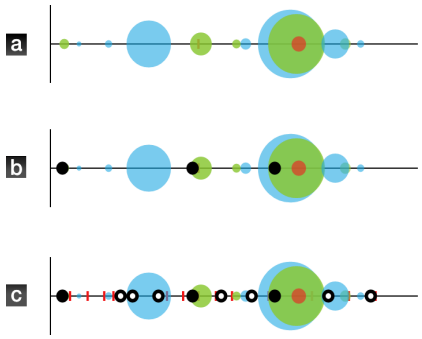

Figure 2. The layers of a Plexline focusing first on directed social child behaviors and then adding additional behavior information. The colored circles in Figure (a) represent the child's socially-directed gaze (blue), gesture (green), and speech (red). The diameter of the circle is proportional to the duration of the annotation. In Figure (b), the examiner's social bids are layered on the timeline as black filled circles. In Figure (c), all other child's actions (hatch marks) and other examiner speech (unfilled black circles) are added to the Plexline.

The examiner's speech is categorized as social bids or verbalization. They are usually social bids, which consist of a question or a demand, such as "Can you turn the page?" or "Look at my hat!" Social bids have a limited range of expected reactions and are marked by small black points on the Plexline (see Figure 2b). They pop out among the colored circles and indicate the start of an interaction. All other verbalizations (except when calling the child's name) by the examiner are visualized as small, unfilled black circles (see Figure 2c).

Visual Design

Plexlines' abstracted approach of using shapes and symbols can be more concrete than numbers. People perceive perceptual structure—patterns of quantities, color, relative size, and shapes—better than patterns of numbers or words [25]. The latter uses single units, while the former operates as a whole through our cognitive ability to quickly perceive spatial relationships.

Through an iterative design process [26], the design of Plexlines was adapted to be heavily informed by the patterns clinicians look for in behavioral coding. Based off of the annotation taxonomy, Plexlines use overlapping circles along a timeline to highlight coordinated behaviors. The temporal nature of the sessions makes it natural to lay the information out horizontally as a timeline [27]. This layout also facilitates comparing a list of Plexlines.

Coordinating Co-occurring Behaviors

The coordination of these three behaviors indicates high social engagement. It is one of the motives behind the choice to use circles to represent the child's behavior. To show coordinated behavior on a timeline, the design must

accommodate overlapping behaviors. After iterating through many visual styles, slightly transparent circular shapes were found to be the most legible for identifying overlapping behaviors with minimal occlusion.

The diameter of the circle scales relative to the duration of the child's behavior. Although this creates a non-linear scale between the area of the circle and the duration of the annotation, exponential scaling assists users in identifying co-occurring behaviors quickly to then explore in more detail. In cases where circles overlap, the smallest circle is always brought to the top to minimize occlusion, regardless of color. Circles are also transparent to allow for ease in spotting overlaps. A clinician interested in complex coordinated behaviors would look for instances of two, or even three, circles of different colors overlapping or lack thereof (see Figure 2c). Examiner speech throughout the RABC is consistent and short, so the circles for the examiner do not scale to duration. They act as anchor points along the Plexline for comparison across multiple Plexlines.

Defining Initiation-Response Stages

Joint attention - characterized by the shared focus of two or more people on one object - is another critical measure of social engagement [28]. The fluidity of back-and-forth interactions is one way to measure joint attention. Much of the RABC centers engagement around objects—a ball, book, and hat. When the examiner presents the object to the child, she is probing for signs that the child is able to identify her intent. Ideally, the child will draw attention to the object by means of gaze, pointing, or verbal behavior to create a shared experience between the child and the examiner.

Examiner bids followed by a series of colored circles (or lack thereof) before reaching the next social probe may be isolated as one initiation-response sequence. One initiation-response sequence shows how soon and how much the child responds to the examiner. A child-examiner pairing that is highly synchronous would have a rhythmic pattern of initiation-response sequences along the entire Plexline (see Figure 1a). The Plexline of a distracted or object-centered child would have extended breaks throughout the Plexline (see Figure 1b).

Building and Exploring A Plexlines Library

In demonstrating Plexlines to our audience, we do it in a browser-based environment that allows them to compare multiple Plexlines (see Figure 3). Facilitating comparison is critical in establishing the baseline metrics and demographic profiles necessary to spot deviations. The interface follows Shneiderman's mantra of "overview first, zoom and filter, then details-on-demand" [29]. Users start by viewing a single child against an archive of all the Plexlines laid out as small multiples for simple comparison [30]. While the visualization is designed to stand alone without video, a video can be loaded with each Plexline. The Plexline acts as a seekbar for navigating the video which is provided to assist in learning and to clarify points of interest that may be confusing.

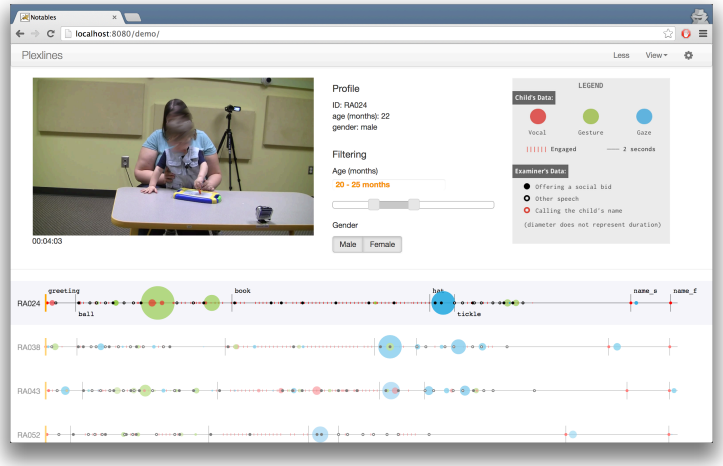

Figure 3. The main view of the webtool with one Plexline selected.

Comparing Apples to Apples

Behavioral development is highly dependent on age, especially in young children. For instance, we do not expect to see much vocalization in children less than 12 months old. Filtering the archive by age and gender in the webtool sets the expectations for what patterns of behavior are common among the age groups. We provide an aggregate view, where all other Plexlines—besides that of the child in focus—are layered on top of each other (see Figure 4). Patterns become even easier to compare when the user places one child's Plexline against an aggregation of all of the other Plexlines in the filtered population of children.

As an exploratory tool, filtering and sorting by certain age groups confirms what we know about developmental milestones and helps identify different trajectories of behavioral development. Aggregation allows clinicians and researchers to create experimental "templates" of behavioral styles and develop predictive patterns of behavior for different populations of children. This is exemplified in the comment, "*I really liked being able to look at one child's performance compared to the [aggregate view] of all the others"* (P5). All of our study participants commented on the value of the aggregate display (see Figure 4), with five commenting it as one of their favorite features. Clinicians further suggested we include aggregate templates for age ranges at three-month intervals and templates for specific behavioral disorders.

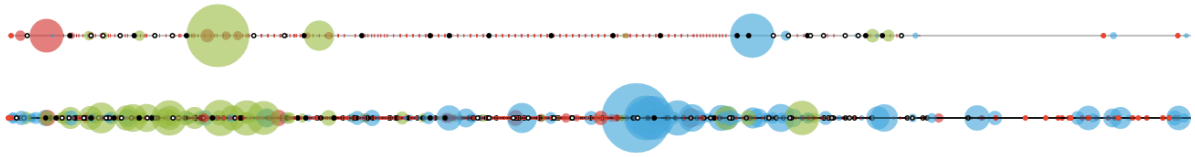

Figure 4. One Plexline compared against an aggregate of the same sequence of events.

Customization

Plexline uses predefined groups for 21 different annotations of child behavior. The directed behaviors are classified into color-coded circles, and the non-directed behaviors are displayed as hatch marks. While we initialize each category for users, the users can customize the Plexline by adjusting these categories. We provide users with a simple drag-and-drop interface that allows them to move the annotated child actions into other categories (see Figure 5). With this functionality, users can tailor Plexlines to their specific needs. If one would like to focus only on one specific child behavior such as pointing, all other behaviors can be removed from the Plexline to show a simplified version highlighting that one behavior. To visualize "gaze at ball" annotations as circles instead of hatch marks on a Plexline, a user can move "gaze at ball" from the others category to the gaze category through the annotation module. The flexibility of the webtool accommodates researchers and clinicians with distinct needs and provides an opportunity for users to delve deeper by showing less.

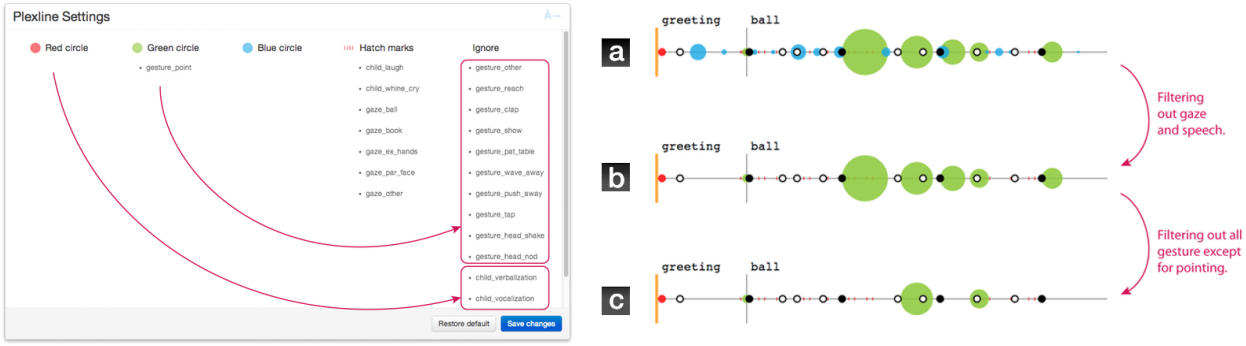

Figure 5. Customization and authoring in the webtool allow the user to change annotation categorizations and simplify Plexline. This image shows three stages of filtering. From top to bottom: (a) all annotations visible, (b) only gestures visible, (c) only one type of gesture (i.e. pointing) visible

Evaluation

To evaluate Plexlines, we recruited eleven (9 female, 2 male) researchers and clinicians with research and/or clinical experience in developmental health, including early childhood education, intervention, and autism research. Six of the participants reported that they had more than five years of research experience. The remaining participants were doctoral candidates.

We began the study with a five-minute introductory video, which explained the details of the RABC, Plexlines, and the webtool. The participants were then given approximately thirty minutes to familiarize themselves with the webtool. During this time, the participants explored the functionality of the webtool and described how they might use it in their workflow. We observed the participants using the tool and recorded notes describing their use of the webtool and Plexlines and any comments they shared while using it. After the subjects explored the webtool, they were given a Plexline comprehension worksheet, which asked the participants to describe the behaviors represented by four different Plexlines without the assistance of video or the webtool. Lastly, the participants were given a survey that included questions to evaluate Plexlines and the webtool, and indicate their knowledge of developmental health and ASD behaviors on a 5-point Likert scale. In addition, we included open-ended questions to list the strength and weaknesses of Plexlines and the webtool. The study lasted roughly one hour for all participants.

Despite our initial concerns that researchers and clinicians would be hesitant to embrace unfamiliar behavioral visualization technologies, Plexlines and the webtool were well received. On a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5), participants rated that they were satisfied with Plexlines (μ=4.11, σ^2=0.33) and the webtool (μ=4.33, σ^2=0.24). We found that the participants grasped the concept of Plexlines quickly, and they were able to make interpretations from the Plexlines.

We used an open-coding method to label and summarize comments and observations while participants were exploring the webtool. We discovered that in general, participants used the following strategies to navigate Plexlines and draw interpretations, going through each stage at different rates depending on their level of familiarity with ASD and their research goals:

1) Rapidly explore the archive through a browsable interface.
2) Compare one child against many using customizable zooming, filtering, and aggregation tools.
3) Interpret Plexlines by spotting specific moments of concern.
4) Use Plexlines as a narrative to share their interpretations of a child.

Exploring the Archive

Facilitated by the webtool interface, the participants initially browsed the library of Plexlines displayed as a list to get an overview of the tool and familiarized themselves with Plexlines. After spending a few minutes browsing, each of the participants in our study independently developed their own search plans for exploring the Plexlines. The goals varied depending on their previous research, clinical experiences, and familiarity with behavioral analysis. Some participants focused primarily on finding patterns among different age groups, while others focused on spotting specific behaviors in children, catered to their own research goals or interests.

Interpreting Plexlines

After the exploration stage, the webtool allowed users to customize the Plexlines display to focus on specific points of interest. One participant described her hypothesis and investigation strategy as such: "*If you are working with children with ASD, the first thing you want to look [for] is gesture and gaze because they usually avoid eye contact and have fewer gestures compared to children with disabilities*" (P10). Participants used relationship comparison and details-on-demand strategies to verify their hypotheses and to make interpretations about the child's activity on the Plexline.

On a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5), participants found Plexlines interpretable (μ=4.22, σ^2=0.39) and exhibited visual literacy of the Plexlines within the first thirty minutes. One participant stated, "*I've been here 15 minutes and already [they're] a lot easier to read*" (P1). Every participant commented on atypical behaviors they observed throughout the Plexlines, and were able to independently pick out a child that was suspected to be at risk for autism. When spotting an outlier, the participants would make remarks that indicated they wanted to pursue a deeper investigation: "*I can see that this guy is not responding to these bids much at all"* (P4), "*I really want to know what is happening with the little girl!*" (P4), and "*RA052 stands out the most*" (P2). Most subjects then spent considerable time on one child, closely inspecting the corresponding Plexline and

using it to scroll to the video to verify their hypotheses. The ability of the participants to identify children in need of further evaluation based solely on a graphic demonstrates the salience of Plexlines.

Participants also distinguished between the subtleties in interaction styles. There was consistent agreement among the participants about what types of behaviors the children were showing at specific times. Four participants also felt comfortable expressing concern for specific children based solely on the Plexline without any video or aggregation for comparison.

Making Comparisons

One popular strategy that the participants displayed was filtering by age and then searching for patterns within the age group. One participant described their process as follows: "*Watching her, I immediately think something is going on. She is making a lot of gestures, she is making sounds, but it is not clear to me what is happening yet, so I am filtering down to a tighter age range*" (P4). The ability to filter profiles and create aggregates for that group proved to be critical for providing the right context for making comparisons. Common filtering strategies include creating profiles by age or focusing on specific behaviors.

Participants were able to quickly glance over the small multiples to make comparisons against other children in the library. One participant wrote that one of the most positive aspects of Plexlines is "*the ability to examine patterns across multiple subjects in one visual field*" (P11). Beyond simple browsing, the aggregate view (see Figure 4) is a popular and effective method for making comparisons. Five participants specifically stated that the ability to view the aggregate was one of the biggest strengths of Plexlines in providing anchors for behavioral expectations. Being able to conduct a data analysis on the whole data set is especially critical in explaining visualizations to other people.

For researchers that were interested in a specific type of behavior, they preferred to filter by hiding all other behaviors besides the ones they are most interested in. The customizability of the annotation schedule allowed the participants to tailor the Plexlines to their expertise. One particular participant adjusted the settings to show only 3 gestures: point, reach, and tap. When asked to explain his process, he said, "*I am interested in gesture because he is trying to say something, but he is not able to vocalize it*" (P11). After spotting an unusual Plexline, participants formed hypotheses about what they thought was happening and confirmed their interpretations by focusing on specific stages of the Plexline.

Using Plexlines to Tell a Narrative

Visualizations can be made even more accessible by allowing the users to filter out noise and frame the information around a narrative [31]. The ability to omit data and break down behavior by type or stage proved to be valuable in telling a story to non-experts. After completing an evaluation session and interpreting the results, clinicians in our study wanted to engage a parent in the next stage decision-making process. In describing something as complicated as behavior, showing is more informative than telling.

As a colorful graphic, Plexlines are less intimidating than a spreadsheet or a number rating. Because of this quality, Plexlines act as a catalyst for discussions between clinicians and parents. A clinician can navigate a Plexline in part or in whole to tell a story with a beginning, middle, and end to the parent through the visualization. In an example situation that a participant gave us, clinicians would "*use it to say, 'Four different times I asked your child to do this and he didn't respond. Our expectation is that with the first or second bid, [the child would respond]*'" (P2). The ability of a graphic to show a causation of events and allow the viewer to discern the relationship among them creates a narrative that engages the reader beyond a text-only report.

To further reduce complexity for the parent, the clinician can break the session down into tasks by segmenting the Plexlines and filtering out unnecessary annotations. For example, parents may have misconceptions about their child's developmental health. One participant gave an example of a parent that believed a highly vocal child indicated no developmental delay: *"A dad linked [social engagement] to language. So let's remove all the vocalization. Let's [focus on] where the child is looking to show a parent"* (P2). By isolating the visual narrative around eye gaze and having a concrete representation of behavior as an artifact for discussion, the clinician can more easily explain her interpretations.

Study participants described telling stories to clinicians, to parents and to research audiences. For example, a researcher stated, *"Once I had done data analysis on the whole data set, I still might present [the] data aggregate and see [the] prototypical [18 months old child that was engaged] like for a talk. Then show a prototypical for a child who is impaired"* (P1). In this same context, the archival capabilities of the webtool allow users to create a

comprehensive story that extends beyond just one child. According to a participant, Plexlines *"display a visual story to others without worrying about confidentiality. Plexlines replaces the need of sharing videos"* (P9).

Discussion and Future Work

Plexlines do not replace the existing evaluation processes, but can assist in understanding child behavior. In general, visualization is an underutilized technique in behavioral science, and Plexlines demonstrates the potential of this approach. From our user feedback, we found that Plexlines complement traditional behavioral evaluation processes, especially by providing salient visualization of social behavior. We identified opportunities to use Plexlines in rapid screening, tracking child development, and training.

Screening a Spectrum of Children

We intentionally did not create profiles of prototypical children because we realize that no two children are alike and there is no such thing as an "average" child. Visually comparing a child to their age group, or even just comparing a child to another is not a trivial task with existing tools. Currently, we suggest how a child might behave by showing the aggregate view, but this can be visually cluttered and misleading. The additive nature of transparent colors exaggerated the characteristics of a typical child, yet we discovered that comparing aggregates and averages was one of the most important exploration strategies, helping the users form frames of reference (see Figure 4). After a few minutes exploring the tool, participants familiar with RABC and had experience with ASD were comfortable stating, "*Here's a good example of a typical kid*" (P1).

While we were initially hesitant to create any Plexlines that are suggestive of an ideal child for a specific profile, the participants' desire for a normative graph with normative data changed our perceptions. A single normative Plexline that is informed by the dataset can be valuable in all stages of the process from exploration to interpretation to sharing. This is an opportunity for us to explore in the future.

Plexlines as a Personal Archive

While our user study focused on the Plexlines, there is room for improvement in making the interface more robust and usable. In particular, we plan on allowing the user to focus on and track the records of a single child. In our dataset, there are several children who were brought back for a follow-up evaluation. These children have two Plexlines in the library. These follow-up RABC sessions open up opportunities to track a child's progress consistently over a longer period of time. This personal record can be used by parents and clinicians to build a cohesive, sharable snapshot of each child as they navigate the child's future, from pre-screening for autism to evaluating the effectiveness of intervention strategies. Users will need the ability to mark and annotate points of interest on the Plexline for later reference. Each added Plexline contributes to a growing archive of Plexlines that help researchers and clinicians understand communicative child development.

In creating such a record, we are exploring Plexlines in other types of behavioral evaluation beyond the RABC. A few of our participants have shown interest in visualizing their own datasets featuring dyadic interaction with Plexlines. We are exploring alternate visualizations for dyadic interaction where one person is visualized above the center line and the other person is visualized below.

Plexlines as a Teaching Aid

Not only are Plexlines valuable for explaining the evaluation process and outcomes to parents, but they can also be used for training clinicians in the RABC. Trainees can see a series of Plexline visualizations to understand a typical session and use the exploration strategies to understand the structure of the protocol and the expected behaviors that follow. Used as an artifact in conversation, visualizations can help improve memory and support interpretations [30]. Several participants commented on the use of Plexlines as a teaching tool. On in particular emphasized that Plexlines can reveal patterns that are difficult to spot in videos: "*I think this would be helpful [for training]. For example, Amy Whetherby's videos for training say what's typical and not typical. [Plexlines let you] see the whole thing - like a condensed ADOS. [I'd go] through an example of what I'm looking for: verbal, nonverbal, social non-directedness. It's a hard skill to train*" (P4).

Limitations

Our approach to visualizing behavior on Plexlines relies heavily on annotation availability. Our current RABC dataset may not contain many cases of children on the autism spectrum. Most children participate prior to a diagnosis. Additionally, the annotations are limited by the accuracy of coding, and the rigidity of the handcrafted annotation schedule. We realize annotations are imperfect and not inclusive of every possible behavior.

Coding schemes improve iteratively over time. The features we are coding may not be optimized for our screening goals, and the taxonomy for Plexlines is highly influenced by the taxonomy of the existing RABC annotations. We currently distinguish between gaze, gesture, and speech behaviors. Smiles and affect are examples of annotations that may be useful, but not yet annotated. Annotations for other red flags of autism, such as echolalia, unusual prosody, and stereotypical repetitive behaviors [31, 7] could also be explored.

The time to code the RABC videos is another limitation. Ideally, a clinician may want to show a parent their child's Plexline immediately following the session. Other members of the research team are exploring vision and audio techniques to automatically extract annotations from the RABC videos. Classification accuracy rates for gaze, speech-like vocalization, smiles, and emotion are improving. Until we can reliably annotate data automatically, we begin by using time-intensive hand-coded annotations for our visualization.

Conclusion

We presented Plexlines, a technique for visualizing multiple layers of socio-communicative behaviors on one timeline. The visual presentation of behavioral data provides researchers and clinicians with a novel way of understanding and interpreting behavioral communicative data beyond traditional charts and tables. While initially fearful that alternative visualizations were not the norm in clinical and research practice, feedback from researchers and clinicians shows that Plexlines serves as an engaging and effective method of providing a compact overview of a person's behavior.

Our study revealed that Plexlines has the potential to be integrated into existing behavioral evaluation processes, aid in the detection of developmental delays in young children, and serve as a visual artifact to better communicate with parents. Through exploration and customization of Plexlines, researchers and clinicians were able to independently identify two children at risk for ASD. Participants used Plexlines to interpret the RABC data and reflect on their own personal research questions. They created stories around Plexlines and imagined using Plexlines to facilitate conversations with parents and larger audiences. Personalizable and shareable, Plexlines aid in expanding our shared understanding of human behavior and child development. While more studies are needed, we envision integrating Plexlines into early screening and clinical evaluations in hopes of increasing rates of early detection for timely intervention, a critical element in minimizing developmental delays among children with ASD [32].

References

1. Rogers SJ, Vismara L, Wagner AL, McCormick C, Young G, Ozonoff S. Autism treatment in the first year of life: a pilot study of infant start, a parent-implemented intervention for symptomatic infants. Journal of autism and developmental disorders. 2014 Dec 1;44(12):2981-95.
2. Robins DL, Fein D, Barton ML, Green JA. The Modified Checklist for Autism in Toddlers: an initial study investigating the early detection of autism and pervasive developmental disorders. Journal of autism and developmental disorders. 2001 Apr 1;31(2):131-44.
3. Shumway S, Wetherby AM. Communicative acts of children with autism spectrum disorders in the second year of life. Journal of Speech, Language, and Hearing Research. 2009 Oct 1;52(5):1139-56.
4. Wetherby AM, Brosnan-Maddox S, Peace V, Newton L. Validation of the Infant—Toddler Checklist as a broadband screener for autism spectrum disorders from 9 to 24 months of age. Autism. 2008 Sep 1;12(5):487-511.
5. Ousley OY, Arriaga R, Abowd GD, Morrier M. Rapid assessment of social-communicative abilities in infants at risk for autism. Technical Report CBI-100, Center for Behavior Imaging, Georgia Tech; 2012 Jan.
6. DeMyer MK, Hingtgen JN, Jackson RK. Infantile autism reviewed: A decade of research. Schizophrenia Bulletin. 1981 Jan 1;7(3):388-451.
7. Wetherby AM, Woods J, Allen L, Cleary J, Dickinson H, Lord C. Early indicators of autism spectrum disorders in the second year of life. Journal of autism and developmental disorders. 2004 Oct 1;34(5):473-93.
8. Bergstrom T, Karahalios K. Seeing more: visualizing audio cues. In Human-Computer Interaction–INTERACT 2007 2007 Sep 10 (pp. 29-42). Springer Berlin Heidelberg.
9. Genest A, Gutwin C. Evaluating the effectiveness of height visualizations for improving gestural communication at distributed tabletops. In Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work 2012 Feb 11 (pp. 519-528). ACM.
10. Jones W, Klin A. Attention to eyes is present but in decline in 2-6-month-old infants later diagnosed with autism. Nature. 2013 Dec 19;504(7480):427-31.

11. Rind A, Wang T, Aigner W, et al. Interactive information visualization for exploring and querying electronic health records: a systematic review. Found Trends Hum Comput Interact. 2013;5:207–298.
12. Wang TD, Plaisant C, Quinn AJ, Stanchak R, Murphy S, Shneiderman B. Aligning temporal data by sentinel events: discovering patterns in electronic health records. In Proceedings of the SIGCHI conference on Human factors in computing systems 2008 Apr 6 (pp. 457-466). ACM.
13. Monroe M, Lan R, Lee H, Plaisant C, Shneiderman B. Temporal event sequence simplification. Visualization and Computer Graphics, IEEE Transactions on. 2013 Dec;19(12):2227-36.
14. Hsu W, Taira RK. Tools for improving the characterization and visualization of changes in neuro-oncology patients. In AMIA Annu Symp Proc 2010 Nov 13 (pp. 316-20).
15. Ozturk S, Kayaalp M, McDonald CJ. Visualization of Patient Prescription History Data in Emergency Care. In AMIA Annual Symposium Proceedings 2014 (Vol. 2014, p. 963). American Medical Informatics Association.
16. Klimov D, Shahar Y, Taieb-Maimon M. Intelligent visualization and exploration of time-oriented data of multiple patients. Artificial intelligence in medicine. 2010 May 31;49(1):11-31.
17. Shahar Y, Goren-Bar D, Boaz D, Tahan G. Distributed, intelligent, interactive visualization and exploration of time-oriented clinical data and their abstractions. Artificial intelligence in medicine. 2006 Oct 31;38(2):115-35.
18. Gotz D, Sun J, Cao N, Ebadollahi S. Visual cluster analysis in support of clinical decision intelligence. In AMIA Annual Symposium Proceedings 2011 (Vol. 2011, p. 481). American Medical Informatics Associatione
19. Stubbs B, Kale DC, Das A. Sim• TwentyFive: an interactive visualization system for data-driven decision support. In AMIA Annual Symposium Proceedings 2012 (Vol. 2012, p. 891). American Medical Informatics Association.
20. Boraston Z, Blakemore SJ. The application of eye-tracking technology in the study of autism. The Journal of physiology. 2007 Jun 15;581(3):893-8.
21. Hashemi J, Spina TV, Tepper M, Esler A, Morellas V, Papanikolopoulos N, Sapiro G. A computer vision approach for the assessment of autism-related behavioral markers. In2012 IEEE International Conference on Development and Learning and Epigenetic Robotics (ICDL) 2012 Nov 7 (pp. 1-7). IEEE.
22. Han Y, Rozga A, Dimitrova N, Abowd GD, Stasko J. Visual Analysis of Proximal Temporal Relationships of Social and Communicative Behaviors. In Computer Graphics Forum 2015 Jun 1 (Vol. 34, No. 3, pp. 51-60).
23. Lord C, Rutter M, Le Couteur A. Autism Diagnostic Interview-Revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. Journal of autism and developmental disorders. 1994 Oct 1;24(5):659-85.
24. Lord C, Risi S, Lambrecht L, Cook Jr EH, Leventhal BL, DiLavore PC, Pickles A, Rutter M. The Autism Diagnostic Observation Schedule—Generic: A standard measure of social and communication deficits associated with the spectrum of autism. Journal of autism and developmental disorders. 2000 Jun 1;30(3):205-23.
25. Arnheim R. Visual thinking. Univ of California Press; 1969.
26. Lee J, Lin S, Karahalios K. Visualizing patterns of social and communicative behavior in children using plexlines. In Proceedings of the 2013 Workshop on Visual Analytics in Healthcare. 2013 Nov (pp. 28-32) – unarchival workshop paper.
27. Aigner W, Miksch S, Schumann H, et al. Visualization of Time-oriented Data. Springer, New York, 2011.
28. Mundy P. Joint attention and social-emotional approach behavior in children with autism. Development and Psychopathology. 1995 Dec 1;7:63-.
29. Shneiderman B. The eyes have it: A task by data type taxonomy for information visualizations. In Visual Languages, 1996. Proceedings., IEEE Symposium on 1996 Sep 3 (pp. 336-343). IEEE.
30. Tufte ER, Graves-Morris PR. The visual display of quantitative information. Cheshire, CT: Graphics press; 1983 Oct.
31. Viégas FB, Boyd D, Nguyen DH, Potter J, Donath J. Digital artifacts for remembering and storytelling: Post history and social network fragments. In System Sciences, 2004. Proceedings of the 37th Annual Hawaii International Conference on 2004 Jan 5 (pp. 10-20). IEEE.
32. Lord C, McGee JP. Educating children with autism. Washington, DC: National Academy Press; 2001.