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TITLE:

Comparing Eye-tracking Data of Children with High-functioning ASD, Comorbid ADHD, and of a Control Watching Social Videos

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KEYWORDS:

ASD, ADHD, eye tracking, area of interests, scanpath, fixation counts, fixation duration

SUMMARY:

This is a qualitative comparative case study analysis of eye-tracking data on the first moments of social video scenes as viewed by three participants: one with autism spectrum disorder, one with comorbid attention deficit-hyperactive disorder, and one neurotypical control.

ABSTRACT:

Children with autism spectrum disorders (ASD) are known to have sensory-perceptual processing deficits that weaken their abilities to attend and perceive social stimuli in daily living contexts. Since daily social episodes consist of subtle dynamic changes in social information, any failure to attend to or process subtle human nonverbal cues, such as facial expression, postures, and gestures, might lead to inappropriate social interaction. Traditional behavioral rating scales or assessment tools based on static social scenes have limitations in capturing the moment-to-moment changes in social scenarios. An eye-tracking assessment, which can be administered in a video-based mode, is therefore preferred, to augment clinical observation. In this study, using the single-case comparison design, the eye-tracking data of three participants, a child with autism spectrum disorder (ASD), another with comorbid attention deficit-hyperactive disorder (ADHD), and a neurotypical control, are captured while they view a video of social scenarios. The eye-tracking experiment has helped answer the research question: How does social attention differ between the three participants? By predefining areas of interest (AOIs), their visual attention on relevant or irrelevant social stimuli, how fast each participant attends to the first social stimuli appearing in the videos, for how long each participant continues to attend to those stimuli within the AOIs, and the gaze shifts between multiple social stimuli appearing concurrently in the same social scene are captured, compared, and analyzed in a video-based eye-tracking experiment.

INTRODUCTION:

Persons with ASD are known to be characterized by behavioral deficits in social communication, based on conventional behavioral evidence from structured observational assessments and parent interviews. In addition, sensory processing abnormalities have been recently incorporated into the DSM-5 diagnostic criteria of ASD[1]. Social information processing involves the lower level sensory-perceptual processing and higher level social cognitive processing of social information. Sensory-perceptual processing refers to the ability to attend to social stimuli and encode them in a short-term memory bank for instant retrieval and response-planning, while social cognitive processing refers to the interpretation of social information by social reasoning and problem-solving[2-3]. As such, social information-processing deficits often lead to other psychobehavioral characteristics, such as social anxiety and inattentiveness. This can be illustrated by the high comorbid prevalence rate of ASD with attention deficit-hyperactive disorder (ADHD). The range of comorbidity for ADHD in ASD has been estimated at 30% to 80%, whereas the presence of comorbid ASD in ADHD has been estimated at 20% to 50%[4].

Two major hypotheses have been put forward to account for the deficits in social information processing—namely, enhanced perceptual functioning (EPF) and weak central coherence (WCC). EPF refers to the overattentiveness to or preoccupation with specific parts by individuals with ASD, whereas WCC refers to their weakness to derive the essence of wholes by pulling together the interelement relationships of the parts[5]. Both theoretical frameworks attest to their failure to globally configure or process the multiple stimuli concurrently presented in a confined social context[6-7]. In an earlier face emotion recognition study using static face expression photos[8], it was found that the ASD group tended to show localized processing of facial features (such as the shape of the mouth) using EPF, but seem to be weaker in configural processing, which demands pulling together the more abstract perceptual concepts as postulated by WCC, such as the spatial relationships between multiple facial components (*e.g.*, the distance between the eyebrows and the intensity of the eye gaze)[9-10].

Since daily social episodes consist of dynamic moment-to-moment subtle changes in social information, any failure to attend or engage in the sensory-perceptual processing of subtle human nonverbal cues, such as facial expression, postures, and gestures, and to make sense of the relationships of the different social stimuli might lead to inappropriate social cognitive processing. Eye-tracking experiments have been increasingly used to supplement clinical observation in social information processing studies. Eye-tracking data, in the form of scanpath patterns, visual fixation counts, and visual duration, have been major biomarkers to investigate social information processing in ASD[11-15].

In this study, we illustrate the use of the eye-tracking technique to investigate whether the two participants with ASD and with ASD-ADHD process the first moments of social video scenes differently than the neurotypical child. The eye tracker equipment captures four major indices during viewing: the number of visual fixations, the first fixation duration, the total fixation duration, and the scanpath patterns in the form of spatial arrangement and sequence of fixation points. In this way, how fast each participant attends to the audio-visual stimuli predefined by AOIs as they first appear into the social scenes, for how long they continue to

look at those AOIs, and their gaze shifts between multiple AOIs appearing concurrently in the same social scene can be captured. Any delay to fixate AOIs during the first moments (*i.e.*, 500 ms) and the trajectory of the scanpaths provide important evidence for data analysis. Representative findings from the qualitative analysis of this single-case comparative study using this paradigm are reported.

PROTOCOL:

Parental and participant consent was obtained during the recruitment process in a primary school and a children service center for ASD in Hong Kong and the study was approved by the university ethical review committee of the Education University of Hong Kong.

1. Use of a Video-based Assessment

1.1. Produce several social videos, about one minute long, that consist of daily life scenarios involving several people in a social context (**Figure 1**).

1.1.1. For **Video 1**, demonstrate the following social scenario. In a crowded cafeteria, a student spots an unoccupied seat that is simultaneously occupied by a lady who is talking on the phone and places her bag on the seat with no awareness of his request.

1.1.2. For **Video 2**, demonstrate the following social scenario. Students are playing a chess game while an unfamiliar student comes too close to watch them playing the game.

1.1.3. For **Video 3**, demonstrate the following social scenario. A boy's painting is ruined when his friend accidentally spills water from a cup on the table.

1.2. Conduct expert reviews of all the videos. Select those social scenarios that are agreed on the most by the experts as containing the actors' intention, emotions, and thoughts through their expressions and gestures.

2. Recruitment of the Participants

2.1. From the pool of participants who satisfied the research inclusion criteria, select and match participants with ASD, with ASD-ADHD, and neurotypical controls using their medical diagnostic reports and the percentile scores of Raven's Standard Progressive Matrices[16].

2.2. Convert their Raven percentile scores to five percentile ranks. Select participants who perform at ranks II or III (average) and exclude those who scored above rank I (above average) or at rank IV (below average).

3. Eye-tracking Experiment

3.1. Experimental set-up

3.1.1. On one side of the eye-tracking room, display the videos on a 23-inch color LCD monitor with a screen resolution of 1920 x 1080 pixels, using an eye tracker at a distance of approximately 60 cm from the participant. Have a research investigator operate the eye tracker from the other side of the eye-tracking room (**Figure 2**).

3.1.2. Have another research investigator sit next to the participant and instruct the participant to look at the screen of the monitor. Place the monitor in front of the child on the other side of the partition and connect to the eye tracker. The choice of eye-tracking equipment, testing environment, and the set-up procedures are previously discussed[17].

3.2. Calibration process

3.2.1. Instruct the participants to watch the calibration dots that set the viewing boundaries across the screen by capturing the eye movements using infrared corneal reflectance technology (**Video 4**). The calibration is properly done if all the green dots or lines fall within the grey circle dots.

3.2.2. Repeat the calibration if some of the green dots or lines do not fall within the grey circle dots.

3.3. Viewing of the videos

3.3.1. Instruct the participant to view the social videos one after another, and capture their eye movement data during viewing using the eye tracker.

4. Data Analysis

4.1. Define and set up the first-moment fixation within AOIs (**Video 5**).

4.1.1. Choose context-relevant targets (face, hands, targeted objects, *etc.*) in their initial 500 ms of appearance in each scene of the video as AOIs (**Figure 3**) and label the AOIs in the information box on the left panel.

4.1.2. Upon the completion of the addition and selection of the AOIs in the current frame, move the cursors in the timeline bar at the bottom panel to the next frame.

4.1.3. Adjust the location and boundary of the AOIs in each frame of the video in the presentation video software of the eye tracker manually as the target areas change in each time frame of the video due to the movement of the people or objects as the story of the social video develops.

4.1.4. Click the **Select** button on the top panel and add new AOIs to the new scene if necessary. If some existing AOIs are present for 500 ms in the current scene (the timestamp of the video

can be checked in the bottom left panel) or if they are not relevant in the new frame in the video, right-click on these AOIs to deactivate them in the new frame.

4.2. Run a statistical analysis of the eye-tracking indices. Follow the steps of statistical data processing on the eye tracker as described below (**Video 6**).

4.2.1. Choose the recordings of the children.

4.2.2. Select the Media file for analysis.

4.2.3. Select from the available videos.

4.2.4. Click **Analyze selected media**.

4.2.5. Choose the **Descriptive statistics** (*e.g.*, Sum).

4.2.6. Choose the dependent measures in **Metrics** (*e.g.*, First fixation duration, visit count).

4.2.7. Choose **Recordings** in **Rows**.

4.2.8. Select **AOI Media Summary** in **Columns**.

4.2.9. Click **Update** to analyze the eye-tracking patterns. The results of the eye-tracking pattern metrics are shown on the screen.

4.3. Create the scanpath of a scene from the eye-tracking data (**Video 7**).

4.3.1. Choose **Visualization** and **GazePlot** in the software.

4.3.2. Select the **Media** and **Recordings** in the left panel for visualization.

4.3.3. In the bottom timeline, move the lower cursor to the beginning of the target scene and move the upper cursor to the end of the target scene.

4.3.4. Make sure **Accumulate** is chosen for the **Data** field to show the accumulative scanpath.

4.3.5. Click **Export** and **Visualization image** to save the scanpath as a separate image file.

REPRESENTATIVE RESULTS:

The eye-tracking data of the three Cantonese-speaking children (with ASD, with ASD-ADHD, and a control) aged between the ages of 7 and 9 viewing three social videos using the aforementioned paradigm is presented here (**Table 1**).

The first fixation duration (per 500 ms target AOI) was longer for the neurotypical child (150 ms) than for the ASD and ASD-ADHD children (both 110 ms). The total fixation duration (per 500 ms target AOI) was shorter for the ASD-ADHD child (120 ms) than for both the neurotypical child (170 ms) and the ASD child (180 ms). The total number of fixation counts (per 500 ms target AOI) was the largest for the ASD child (4.62), second for the neurotypical child (4.09), and the shortest for the ASD-ADHD child (3.19).

A scanpath plot captures the visual scanning of multiple AOIs in a social scene. An example of the scanpaths of the three children for one 10 s episode in **Video 1** is shown in **Figure 4** and **Videos 8** - **10**.

FIGURE AND TABLE LEGENDS:

Video 1: Social scenario one. In a crowded cafeteria, a student spots an unoccupied seat which is simultaneously occupied by a lady who is talking on the phone and places her bag on the seat with no awareness of his request.

Video 2: Social scenario two. Students are playing a chess game while an unfamiliar student comes too close to watch them playing the game.

Video 3: Social scenario three. A boy's painting is ruined when his friend accidentally spills water from a cup on the table.

Video 4: Eye tracker calibration process.

Video 5: The process of selecting the target AOIs in the social videos.

Video 6: The process of conducting statistical analysis.

Video 7: The process of creating the scan path of a scene.

Video 8: Scanpaths of the control.

Video 9: Scanpath of the child with ASD.

Video 10: Scanpath of the child with ASD-ADHD.

Figure 1: An example of essential social scenes in Video 1. In the first scene, the boy is waiting to get his meal from the cafeteria staff. In the second scene, he is looking for a seat near the lady who is talking on the phone. In the third scene, he asks the lady whether he can sit on the empty chair next to her. In the last scene, the lady does not notice his request and puts a bag on the unoccupied chair. The boy is disappointed because he could not find a place to sit.

Figure 2: Eye-tracking experimental set-up. A research investigator gave instructions to the child about viewing the videos in front of the monitor on one side of the eye-tracking experiment room. The display of the videos was controlled by another investigator using another computer on the other side of the same room separated by a partition.

Figure 3: An example of the target AOIs in Video 1. The colored ovals are the AOIs (*i.e.*, face, eyes, mouth, hands, mobile phone, and the bag of the lady) that show the first moments in one of the scenes in **Video 1**.

Figure 4: Scanpaths of the control (top), the child with ASD (middle), and the child with ASD-ADHD (bottom). Taking a social scene in **Video 1** as an example, the blue dots trace the scanpaths for the neurotypical control child, the green dots for the ASD child, and the red dots for the ASD-ADHD child. The dots in the figure indicate the locations of the visual fixations. The bigger the dots are, the longer the child attend to that particular spot on the visual stimulus. The numbers in the dots represent the sequence of visual fixations within 500 ms of the video scene.

Table 1: Descriptive statistics of the eye-tracker measurements of the three children.

DISCUSSION:

The first-moment fixation duration was shorter for the ASD-ADHD and ASD children than for the neurotypical child. The total fixation duration was shorter for the ASD-ADHD child than for the neurotypical child, demonstrating a general reduction in visual attention to social stimuli. This showed that the ASD-ADHD child showed a delay in attending to the entry of social stimuli in a social scene. This delay might cause the child to skip registering important momentary social information, which may lead to the misinterpretation of social information and subsequent social cognitive processing.

The total number of fixation counts was lower for the ASD-ADHD child than for the neurotypical child, while the total number of fixation counts within localized AOIs was the highest for the ASD child. This seems to support past ASD findings under the framework of enhanced perceptual functioning (EPF), which suggests that children with ASD employ featural processing; hence, they visually attend to more details of the AOIs then neurotypical controls do.

When the results of the three children are compared, it shows that the ASD child performed the fewest scans across multiple AOIs of social stimuli. This might be explained by the difficulty experienced by the ASD child in pulling together the relationship between relevant social stimuli. This can be accounted for by the weak central coherence theory (CWW), which states that ASD shows deficits in sensory perceptual processing which demands simultaneous attending to and scanning between multiple AOIs.

For scanpath analysis, several limitations are noted. Even though the same scanpath picture is used, it actually contains different scenes within a temporal period (in this study, it was predefined as a video length of 10 seconds). Therefore, there might be spatial errors of gaze

spots on the scanpath plot that do not necessarily represent the actual locations of what the participant is focusing on the plot (**Video 7**). Investigators need to be cautious of these potential eyeballing errors during data analysis and interpretation.

Since the AOIs have to be marked manually on the eye tracker, there might be a latency of visual fixation from the markers themselves. Since the AOIs were manually plotted against the moving social stimuli, there might be slight errors in the duration of how long each AOI lasts across all AOIs. For example, for a predefined 500 ms, an AOI may have been marked for 498 ms or 510 ms. This may make the comparison of performances across different videos, in contrast to that in the same video, difficult as the performance baselines differ from one video to another. Nonetheless, this artifact will have the same impact on all three participants, and therefore, this may not create a bias for a particular type of participant.

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DISCLOSURES:
The authors have nothing to disclose.

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Figure 1. An example of essential social scenes in video one

Figure 2. Eyetracking experimental set up

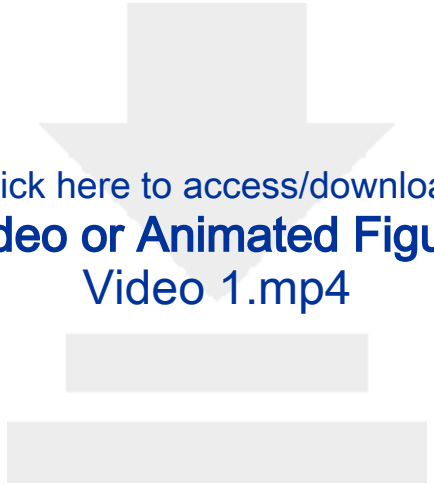
Click here to access/download;Figure;Figure 2.png

Figure 3. An example of the target AOIs in video one

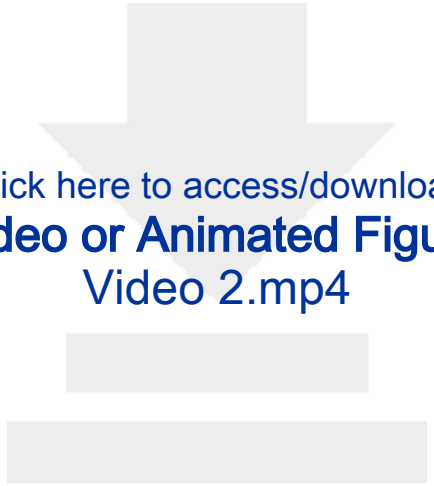
Click here to access/download;Figure;Figure 3.png

Figure 4. Scanpaths of Control, ASD and ASD-ADHD comorbid child

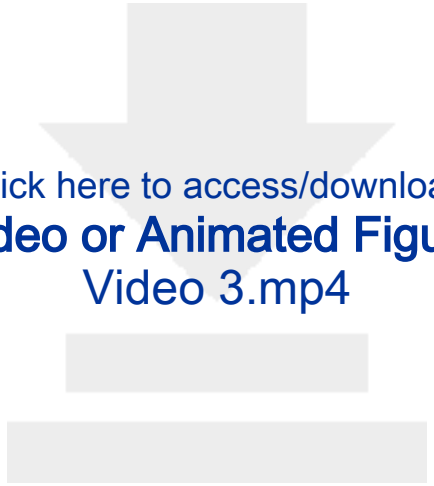
Video 1. Social scenario one



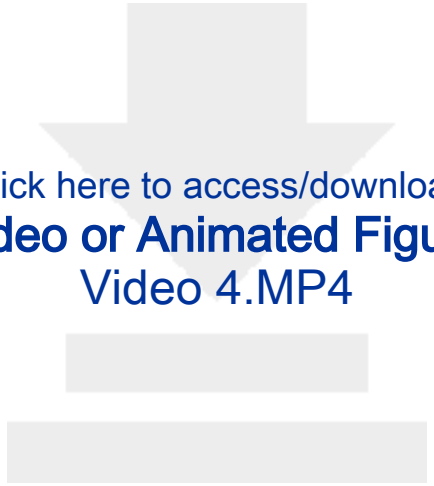
Video 2. Social scenario two



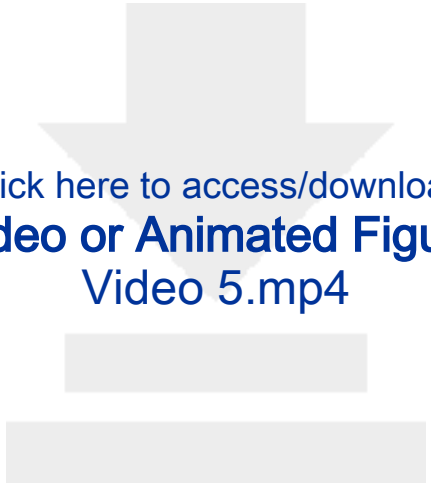
Video 3. Social scenario three



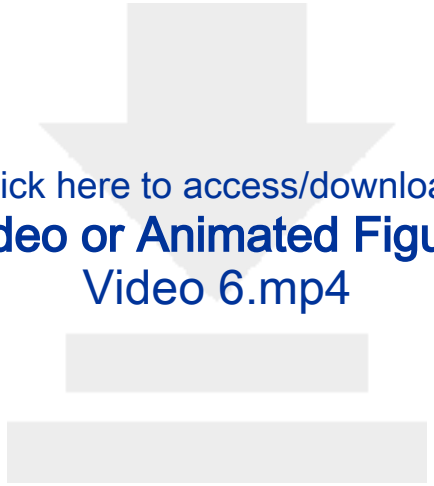
Video 4. Eyetracker calibration process



Video 5. Process of selecting the target AOIs in the social videos



Video 6. Process of conducting statistical analysis



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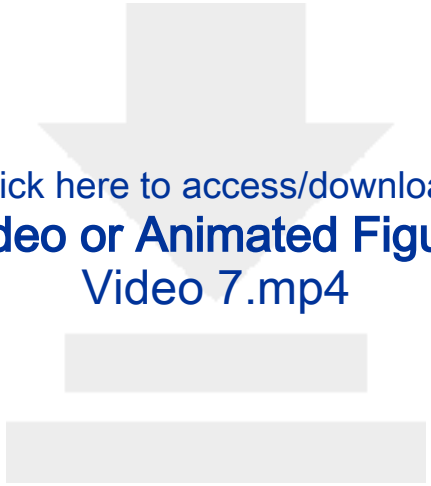
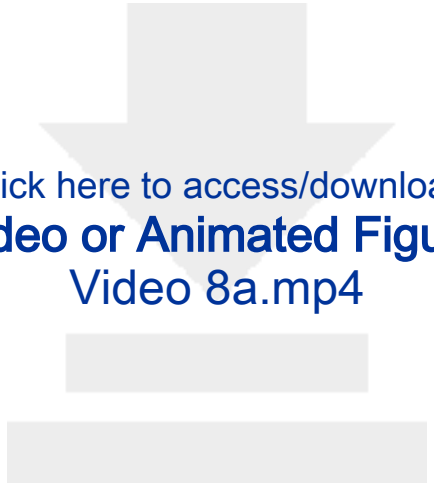
Video or Animated Figure

Video 6.mp4

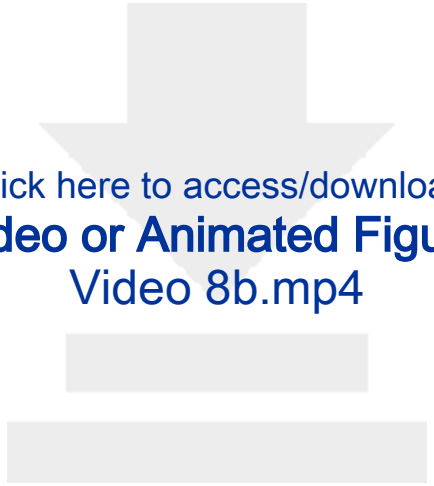
Video 7. Process of creating the scanpath of a scene



Video 8. Scanpath of the neurotypical control viewing a scene in Video 1



Video 9. Scanpath of the ASD child viewing a scene in Video 1



Video10. Scanpath of the ASD-ADHD comorbid child viewing a scene in Video 1

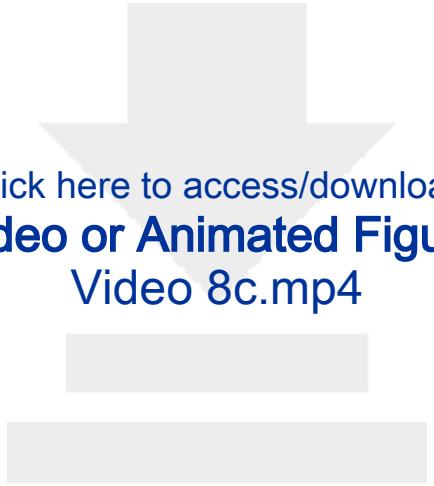


Table 1. Descriptive statistics of the eye-tracker measurements of the three childre

Participant groups	Raven Score	Grade	First fixation duration (ms)
Control	120	3	150
ASD	129	1	110
ASD-ADHD	115	3	110

n.

Total fixation duration (ms)	Fixation counts
170	4.09
180	4.62
120	3.19

Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Tobii Pro TX300	Tobii	N/A	Screen based eye-tracker (300Hz refreshing rate)
Tobii Pro Studio	Tobii	N/A	Software for analyzing eyetracking data

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Date:	June 11 2018

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REBUTTAL - JoVE manuscript submission by Vicky Tsang and Patrick Chun Kau Chu

No.	**Editorial Comments**	**Authors' Responses & Actions taken**
1	Please take this opportunity to thoroughly proofread the manuscript to ensure that there are no spelling or grammatical errors.	The manuscript has been proofread and checked for spelling and grammatical errors.
2	Protocol Language: The JoVE protocol should be almost entirely composed of numbered short steps (2-3 related actions each) written in the imperative voice/tense (as if you are telling someone how to do the technique, i.e. "Do this", "Measure that" etc.). Any text that cannot be written in the imperative tense may be added as a brief "Note" at the end of the step (please limit notes). Please re-write your ENTIRE protocol section accordingly. Descriptive sections of the protocol can be moved to Representative Results or Discussion.	The whole section has been rewritten using the imperative tense and the descriptive sections of the protocol has been moved to Representative results.
3	Protocol Detail: Please add all specific details (e.g. button clicks for software actions, numerical values for settings, etc) to your protocol steps. There should be enough detail in each step to supplement the actions seen in the video so that viewers can easily replicate the protocol.	The steps in 3.2 and 4.1 regarding the eyetracker calibration and the selection of AOI in the video have been expanded.
4	Protocol Numbering: There must be a one-line space between each protocol step.	A one-line space has been added between each protocol step.
5	Protocol Highlight: Please highlight ~2.5 pages or less of text in yellow, to identify which steps should be visualized to tell the most cohesive story of your protocol steps.	The steps that should be visualized has been highlighted in yellow.
6	Discussion: 1) Please ensure that the discussion covers the following in detail: modifications and troubleshooting, limitations of the technique, significance with respect to existing methods, future applications and critical steps within the protocol.	We have modified the content in Discussion further, please see the red parts.
7	Please remove the numbered list from the discussion.	The numbered lists have been removed from the figure.
8	Figures: All panels of a figure (e.g. a,b,c should be on one page).	Figures 4a-c has been combined into one single figure in one page.
9	Figure/Table Legends: Please expand the legends to adequately describe the figures/tables.	The legends have been expanded for Figures 1, 2, 4 and 6.
10	Please define all abbreviations at first use.	The full form has been defined for ASD, ADHD and AOI at first use in the summary, abstract and the main text.
No.	**Reviewer #1**	
11	Number of participants - should discuss this limitation	The manuscript is meant to be a case comparison report. So no group data is reported.
12	In Introduction, the authors may frame the present work as studying "social attention".	Thanks for the suggestions and information. Social attention has been used and related references added to the manuscript.
13	There are several studies along the same line of the present work using videos and the authors should be aware of these research	Thanks for the comments and information. The references such as Klin et al. (2002) and Byrge et al.

	before claiming "There have not been much research done on dynamic social videos".	(2015) have been added in the introduction and the sentence removed.
14	The authors need to carefully check the abstract — there are many grammatical errors, especially there is a mixture of tenses. The present version of abstract does not read smooth to the reviewer.	Thanks for the suggestions and comments. The manuscript has been proofread and checked for spelling and grammatical errors.
	Reviewer #2	
15	While the title is about scan paths, there seems to be more time spent discussing other types of measures … and little is said about how to conduct systematic analyses on scan path data… It is also unclear how this stands out from the article by Sasson & Elison (2012) and what methodology it is adding (perhaps detailed approaches to analyzing scan paths would have added a novel part to the current work).	Thanks for the suggestions and comments. Some details on the creation of gazepath have been added in 4.3 and the title have been changed to "A comparison of eyetracking data of social videos between children with high functioning ASD, comorbid ADHD and control" to include scanpath analysis as one of the components of eyetraking data. One major difference between the current article and Sasson & Elison (2012) is the introduction of the methodology in using social videos and the detailed delineation of its relevant target AOIs for analysis.
16	… if the authors want to go in the direction of a case study/qualitative analysis on scanpaths, the article would need to be completely re-conceived.	Most of the article has been rewritten and restructured. Please see the changes in red.
17	This article feels a bit all over the place and does not have a strong and clear story thread that the reader is following to understand what this work is contributing above and beyond past work (e.g., Sasson & Elison, who are cited by the authors), especially based on the Introduction.	The major contribution of this article is the introduction of target AOI analysis on dynamic social videos when compared with the viewing of photos which are described in most of the previous literature. This is emphasized in the revised abstract.
18	This entire manuscript needs to be revised for English language, as at least half of the sentences are difficult to interpret because of language-related issues (word choice, grammar, etc).	The manuscript has been proofread and checked for spelling and grammatical errors.
19	In the Title and Abstract, there is no mention of children, but this study is with 1st - 3rd graders… but it is confusing, as this study is clearly about children.	In the title and abstract, the word "individuals" is changed to "children" following Reviewer's suggestions.
20	In the Abstract, there is no mention of ADHD +ASD…The Introduction says nothing about ADHD (e.g., why are you including a subject with comorbidity, what is expected to differ, what has past work shown). It is also unclear the point of getting into detail about the three theories if you don't re-visit any of that or use it to make any predictions about your data.	Relevant details about the comorbid ASD-ADHD group have been added in the abstract and the introductions; and, the theories have been revisited in the introduction and discussion sections.
21	Final paragraph of Intro discusses 'comparative case study approach' but then the article takes a more traditional statistical analysis approach, despite having only 3 subjects. Again, speaks to the confusion about the authors' intention behind this article.	This article follows the single-case study approach and the regression section has been removed to make our study aim clearer to readers.

22	I think there is something about scan paths and using more qualitative approaches (combined with quantitative) that could be interesting, but there isn't much at all said to the reader about how to do scan path analyses, whether qualitatively or quantitatively, only about more traditional metrics (# fixations, first fixation duration, total fixation duration).	Details on how to do scanpath analysis have been added in 4.3.
23	In fact, in the Discussion, it mentions a set of reasons why those kinds of analyses are extremely difficult, especially when using video stimuli with complex social scenes, again causing the reader to wonder what the authors are trying to teach the reader, etc, and why they would use a method full of error, as they say.	We purposefully added the limitations in eyetracking procedures as this is specifically requested in JoVE manuscript guidelines. Therefore we reported this to let future researchers aware of its limitations should they desire to conduct similar procedures.
24	Results/Table 2 - No statistical analyses of other more quantitative aspects of eye-tracking can be properly looked at with three children across three groups. If this paper is about 3 subjects, it has to be a case study/qualitative approach, and it makes no sense to do any sort of inferential statistics when there is an n=1 for each group.	We have removed the regression table from the results and focused on qualitative analysis in our revised report.
25	Discussion 2.2 is first moment mentioning anything about the parts of the videos involving people vs. not, and if this is important or worth explaining, it should come up earlier in choices about the videos and the AOIs used, etc.	Thanks for the reviewer's suggestions. We have added a detailed section on defining and setting up the first moment fixation within AOIs in section 4.1 with a video illustration.