ABSTRACT

Hooge et al. [1] asked the question: "Is human classification by experienced untrained observers a gold standard in fixation detection?" They conclude the answer is no. I have had a close look at their data and their report, and I find that both the data itself and the method of presentation of the data to the human raters are problematic. I think that data used to address this important question should be very high quality, and the method of presentation of the data should be optimized. The Hooge et al. [1] study does not meet this standard. A number of fixations have clear saccades within them. No expert human rater would intentionally include such saccades in fixations. Something has gone wrong. Also, the treatment of some inter-fixation intervals as saccades that might have been identified by human experts is completely unjustified. The results regarding these saccades are without merit or meaning.

1 Introduction

Hooge et al. [1] studied human classification of eye-tracking data. They were specifically interested in the classification of fixations. They concluded that human fixation classification cannot be considered a gold standard. I recently had a close look at all of their eye-movement data for an unrelated reason. What I saw surprised me. In my view, some of the data and analysis was unsuitable to support such an important conclusion. I felt it was important that other researchers be made aware of this.

In that paper, they provide minimal illustrations of their signals. Specifically, they illustrate one second of data, from one subject, from a total of 352.2 seconds from 70 subjects (0.28% of the recordings). In the present report, I illustrate more than 60 seconds from more than 14 subjects.

2 Method Details for Hooge et al. (2018)

In describing their data, the authors state:

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1 The eyetracking data for [1] are available here: https://doi.org/10.5281/zenodo.838313
2 To see all of the signals from the Hooge et al. (2018) study, as classified by rater MN, see https://digital.library.txstate.edu/handle/10877/9176. OriginalHoogeStyleFiguresAsPNG.zip are in .png form and OriginalHoogeStyleFiguresAsFIG.zip are in the MATLAB native .fig file form.
“Twelve experienced but untrained human coders classified fixations in 6 min of adult and infant eye-tracking data.” (page 1864)

Within this manuscript, we will be exclusively employing the fixation classifications of a single coder, Marcus Nyström, (“MN”). Dr. Nyström is an internationally recognized expert in eye movement classification.

and the authors also state:

“The eye-tracking stimulus set consists of 70 trials of eye-tracking data measured with a Tobii TX300 at 300 Hz. We used eye-tracking data measured from the left eye. Ten of the 70 trials contained 150.1 s of eye-tracking data of two adults looking at Roy Hessels’s holiday pictures taken in the arctic area around Tromsø, Norway. The other 60 trials contained 202.1 s of eye-tracking data of infants performing a search task [2].” (page 1867)

Details of the scoring are also described:

“Trials of both the adult and the infant eye-tracking datasets were presented in random order on a 24-in. TFT screen (1,920 X 1,200 pixels). The vertical axis of the position signals was fixed (respectively, 0–1,920 and 0–1,080 pixels, since measurements were done on the HD screen of the TX300). ...Each screen showed 1 s of data and contained the last 250 ms of the previous display (to provide context) and 750 ms new data at a time.” (page 1867)

In a personal communication with Dr. Hooge, I was informed that: “We did not use a forehead and chinrest.”

Also, I made the following observations of the data: Adult data consisted of approximately 4500 samples (range: 4499 - 4504, approximately 13.5 seconds). Most infant recordings (46/60) consisted of approximately 1200 samples (range: 1203 - 1210, approximately 3.6 seconds), but 14/60 recordings had very short recordings (median of 312.5 samples, approximately, 0.94 seconds) with a range of 157 - 769 samples. None of these 14 short recordings are plotted in the present report.

Finally, I would like to note that the word “calibration” does not appear in the original article or the readme file distributed with the data. If the eye-movement data were calibrated, it would have been useful for the authors to mention this fact and provide some details. Perhaps, because the signals are presented in pixel units rather than degrees of visual angle, no calibration was employed.

3 Results

3.1 Examples of Good Recordings

Some of the adult and infant recordings looked very reasonable (Figures 1 and 2). Generally, the data from adults looked reasonable. As we will see, the infant data are more problematic.
Fig. 1. This is a good recording from an adult subject (adult-4598375979225964144). The top panel represents horizontal position, in pixels. It is scaled from 0 to 1,920, which matches the scaling [1] used for the hand classification task. The x-axis is scaled in milliseconds. The bottom panel represents vertical position, in pixels. It is scaled from 0 to 1,080, which also matches the scaling used for the hand classification task. Both plots represent approximately 13.5 seconds of data.
3.2 Out-of-Range Values

As noted above, for the human classification of these recordings, the eye position was represented in pixels. The horizontal position signal was scaled to go from 0-1920 pixels and the vertical position signals was scaled from 0-1080. I have found that, in some cases, a substantial amount of the signal, and in particular, the vertical position signal, is out of the presented range. Table 2 lists all of the studies where more than 100 samples were out-of-range. Figure 3 (below) illustrates 4 such cases.
Table 1: List of Studies with More than 100 Out-of-Range Samples

| Data Set            | Number of Out-of-Range Samples |
|---------------------|---------------------------------|
| infant-4601345468058933046 | 639                             |
| infant-4606386303357509649  | 539                             |
| infant-4597253268938977956  | 528                             |
| infant-4603602825832748254  | 411                             |
| infant-4593441564971508404  | 341                             |
| infant-4606604723864184111  | 313                             |
| infant-4604530757509485450  | 307                             |
| infant-4595343491140989604  | 275                             |
| infant-4597178908827295404  | 235                             |
| infant-4584726578059882688  | 218                             |
| infant-4605631479618949368  | 212                             |
| infant-4604305481598970292   | 157                             |
| infant-4595653501593606004   | 103                             |

Fig. 3: Four examples of infant recordings with out-of-range values. The red dots indicate where vertical position data is larger than 1080. In D, the blue dots represent horizontal positions larger than 1,920. The green dots represent data from the vertical channel that is less than 0.0, and thus out-of-range. The red signal and the blue signal appear to be actual eye movements and not artifact. Visualization of this data would provide a human rater with some useful additional information.
3.3 Infant Recordings with Missing Data

A large number of these recordings have a great deal of missing data. Table 2 lists the 19 of 60 infant recordings with more than 25% missing data. Figures 4 and 5 illustrate the 8 infant recordings with more than 70% missing data.

Table 2: List of Subjects More than 25% NaN Values

| FileName                | N_NaN | Percent_NaN |
|-------------------------|-------|-------------|
| infant-4603026287769552265 | 1135  | 94.347      |
| infant-4601213487207749474  | 1075  | 89.212      |
| infant-4607024019025466472  | 1009  | 83.874      |
| infant-4606050638313716974   | 1002  | 82.947      |
| infant-4603997294600609666   | 955   | 79.253      |
| infant-4607158533597356135   | 933   | 77.427      |
| infant-4597078871350441716  | 842   | 69.934      |
| infant-4585006770229471040   | 840   | 69.825      |
| infant-4590914421796899792   | 746   | 61.96       |
| infant-460414452347604331    | 699   | 58.008      |
| infant-4599348903986769270    | 639   | 53.073      |
| infant-4603403341432416855   | 514   | 42.62       |
| infant-4606305162693909260    | 511   | 42.442      |
| infant-4592207091392917904    | 491   | 40.612      |
| infant-4591350692076781768    | 455   | 37.759      |
| infant-4605410513238776168    | 372   | 30.846      |
| infant-4606003927763488057    | 364   | 30.258      |
| infant-4604305481598970292    | 342   | 28.288      |
| infant-4605849449150400922    | 315   | 26.033      |
Fig. 4: Four infant recordings with between 83% to 94% missing data.

Fig. 5: Four infant recordings with between 70% to 79% missing data.
3.4 Saccade-Based Evidence

In [1], the authors state:

"We asked the coders to mark fixations and not saccades, however between the majority of the fixations, saccade candidates are located. To find these saccade candidates we took periods of data between fixations with durations shorter than 100 ms and no data loss. This duration criterion is a liberal one; large 30 degree saccades last about 100 ms [3]. From here on, we will refer to these intervals as saccade instead of saccade candidate.” (page 1881)

The authors then go on to treat this “saccade” data as if the saccades were marked by expert human raters. They argue that disagreements between human coders in classifying these “saccades” is further evidence that human classification is not a gold standard. I had a close look at these “saccades.” I use the same criteria as above (durations shorter than 100 ms and no data loss). (I included such events that ended the recording.)

Of the 540 events, there were a number of candidate saccades that had very non-saccade-like trajectories. To detect such events automatically I followed the steps in Algorithm 1. See Figure 6 for 3 illustrations of this procedure.

Algorithm 1: Steps to Identify Poorly Formed Events treated as if they were Saccades by the Hooge et al. (2018) [1] Authors

1. Determine the position difference between each sample and the prior sample for horizontal and vertical channels \((x_t - x_{t-1})\). These values are the instantaneous velocity in units of degrees per sample. (To get degrees per sec, multiply by the sampling rate (300).

2. Compute the radial velocity \((Vel_{rad})\) as \(\sqrt{Vel_x^2 + Vel_y^2}\). (Figure 6B, upper panel)

3. Integrate the radial velocity (degrees per sample) to estimate the shape of a radial eye-position saccade from the data. (Figure 6B, lower panel, black line)

4. Use [4] to estimate the form of a theoretical saccade, using the time and amplitude of the radial saccade. (Figure 6B, lower panel, red line)

5. Zscore transform both the radial saccade and the theoretical saccade.

6. Subtract the theoretical saccade position values from the radial saccade position values and save them as residuals.

7. Sum the absolute value of the residuals and divide by the number of samples to get a Residual-Per-Sample metric for each candidate saccade.

8. Sort candidate saccades by their Residual-Per-Sample metric.

9. Illustrate some well formed and poorly formed saccades found in this way (Figure 6).

10. Plot the trajectories of all 540 “saccades” sorted by the decreasing Residual-Per-Sample metric\(^3\). (Figure 7)

I took the zscore of both the radial saccade and the theoretical saccade (Step 5 in the above algorithm) because I was not interested in finding events that were too large or too small, but events which differed in terms of the shape of the saccades.

\(^3\)The code for estimating theoretical saccade trajectories used below is at: https://www.mathworks.com/matlabcentral/fileexchange/62880-saccade-model-a-parametric-model-for-saccadic-eye-movement
Fig. 6: Detection of a Ill-Formed Saccades. (A+B: Well formed saccade, C+D and E+F, poorly formed saccades.) (A) The horizontal position and vertical position of an event considered as a “saccade” by [1]. The recording name containing this saccade is in the title of the figure. The low residual per sample (0.07) indicates that this is a well shaped saccade. (B) Illustrates steps in the process of determining if the event trajectory is consistent with a saccade (see Algorithm 1). Analysis pertains to saccade shown in A. Upper Panel: Radial velocity of the saccade. Lower Panel: Saccade trajectory constructed from integrating the velocity signal (black), and a trajectory from the saccade equation provided by [4] (red). (C,D,E,F) Analysis of 2 other “saccades” that have very high residual-per-sample values and are obviously very poorly formed saccades.
In the case of the event displayed in Figure 6 (C and D), there is no evidence of a saccade. In the case of Figure 6 (E and F), there is a saccade but its start and end are obviously marked incorrectly. This was true in many of the “saccades” indicated by this coder’s fixations (MN). Figure 7 shows the third of 90 pages presenting all the 540 saccades (6 saccades per page). The third page was chosen for illustration based on the variety of trajectories. There is no evidence of a saccade in panels A and B. Panels C and D contain saccades, but no expert human rater would ever mark these saccades to include all of the signal in these plots. At least 3 of them start too soon and all of them end much too late. I have looked at every saccade based on coder MN’s data. I may not be a an international expert on saccades, but I have spent a lot of time marking the starts and ends of saccades in such recordings. I would not consider any of saccades on the first 58 of 90 pages to be properly marked. I did find one reasonably properly marked saccade on 14 different pages (59, 64, 65, 68, 69, 72, 75, 76, 83, 84, 85, 88, 89, 90). That is, I agree with the chosen starts and ends of these saccades in 14/540 cases (2.6%). Obviously, different coders may find more or fewer events to be properly marked. Readers are encouraged to try this for themselves. But, in my opinion, there is no way that any eye movement expert would ever consider that more than 10% of these events to be properly marked saccades.

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4See AllPages_01_45.pdf and AllPages_46_90.pdf at https://digital.library.txstate.edu/handle/10877/9176
Fig. 7: This is the 3rd of 90 pages illustrating all events considered as saccades by Hooge et al. (2018) [1]. This page was chosen for illustrative purposes. All of the pages are available (see footnote 3). The first 2 events, A and B, are not saccades. The other panels C-F contain saccades, but the start and end of these events are clearly not correct.

3.5 Mismarks

There are a number of “fixations”, as indicated by coder MN (the only coder examined) that contain obvious saccades (Figures 8, 9, and 10). No eye movement expert would ever intentionally include such saccades in fixations. There must be some kind of mistake. To find these I found the maximum change in the horizontal direction and the vertical direction during each fixation. I then expressed this as a percentage of the range of each signal (Hor: 0-1920, Ver: 0-1080). Fixations with any missing data were not included in this analysis. For one study in particular (Figure 10), 21 of 37 fixations had percent changes greater than 5% (for vertical,
The majority of “fixations” marked in this data set have obvious saccades in them (Figure 10).

Figure 8: Eye movement signals for infant data set “infant-4606305162693909260”. This figure is a cropping of the data figures as drawn by the code distributed with the data (see footnote 1). Although the plots are labeled in units of degrees, they are, in fact, in units of pixels. Fixation periods are in grey. The top plot is the horizontal signal and the bottom plot is the vertical signal. The dashed green vertical line marks the 500 msec time point (a feature I added to the plots). The saccade amplitude for the saccade indicated by the arrow is 11.2% of the horizontal range and 31% of the vertical range. (Note that the entire potential signal range is not shown.). There are 3 other fixations in this recording that contain obvious saccades.
Figure 9: Infant data set “infant-4585006770229471040”. See caption for Figure 8. The saccade amplitude for the saccade indicated by the arrow is 18.9% of the horizontal range.

Figure 10: Signals from adult data set “adult-459787195535632108”. The first 7 “fixations” are shown. The 6 arrows indicate obvious saccades.
4 Discussion

If I were trying to answer the question: “Is human classification by experienced untrained observers a gold standard in fixation detection?” I would not use data from infants. Some of the infant data look scorabble, but too much of it is problematic. And this is such an usual case – the vast majority of eye movement studies are conducted in adults. A PubMed search of all papers with the phrase “eye movement” in the title produces 2562 article listings. The same search with the word infant anywhere in the title, abstract or article meta-data produced 70 articles, or 2.73%.\(^5\)

I would try to conduct the study using the highest quality data I could find. If I still concluded that human classification was not good enough, this would be more convincing to the research community. Otherwise, my work would be open to the criticism that the human raters might have done better with better data. I would collect my data with both head and chin restraint. Such restraint will minimize head movements and keep the participant in focal range of the video camera. I understand that this might be impossible with infants – all the more reason not to use this population. I would present my position signals in degrees of visual angle, rather than pixels. Units of degrees of visual angle are comparable across different eye tracking devices, and are the eye position units most commonly employed in viewing eye movement signals, in my experience. These units do provide additional information for coders, which is in keeping with giving the human coders the best chance to be a gold standard. My colleagues and I have also found that scaling both the horizontal and vertical channel to have exactly the same range of visual angle is also useful for a human coder making judgements about the presence and timing of saccades. I would also try to be as transparent as possible about the data quality of my study, and include a number of figures illustrating the range of quality of the recordings.

I would present my data so that all of the recorded signal that was not artifactual was displayed. I think the out-of-range signal problem was probably related to the lack of head restraint. (Perhaps some sort of calibration procedure might have prevented this problem.) I would certainly not include subjects with more than 50% missing data. I note that in the algorithm of [5], records with more than 20% missing data were marked as “noise trials”. If 46 of 60 subjects had complete data (3.6 seconds) and 14 had, on average, less than 1/3 of a complete data set (median 0.9 seconds), I would exclude those short recordings.

The authors of [1] considered certain inter-fixation periods as if they were human-classified saccades. They then note that the minimum saccade amplitude thresholds for these events varied between coders. This is taken as evidence consistent with the notion that human raters are not a gold standard. I have shown that the vast majority of these inter-fixation periods are simply not properly marked saccades. Therefore, the section in [1] entitled ”Modelled parameters: Minimum saccade amplitude” and the associated data presented in Figure 5 of [1] are wholly without merit or meaning.

There are a number of “fixation” periods, as labelled by coder MN, that clearly have saccades in them. No expert human rater would mark events with these clear saccades in them as periods of fixation. Something has gone wrong here and it needs to be tracked down.

5 Acknowledgements

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Conflict of interest

I have no conflict of interest.

References

[1] Hooge, I. T. C., Niehorster, D. C., Nystrom, M., Andersson, R., and Hessels, R. S. (2017). Is human classification by experienced untrained observers a gold standard in fixation detection? Behavior Research Methods. 50(5), 1864-1881 https://doi:10.3758/s13428-017-0955-x

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\(^5\)PubMed is at https://www.ncbi.nlm.nih.gov/pubmed/. First search was “eye movement [ti]” and the second search was “eye movement [ti] AND infant.”

\(^6\)code available at: https://www.humlab.lu.se/en/person/MarcusNystrom/.
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