White Paper

Tobii® Technology

Determining the Tobii I-VT Fixation Filter's Default Values

Method description and results discussion

Augusti 28, 2012

Abstract

In Tobii Studio 2.3 a new fixation filter was introduced, i.e. the Tobii I-VT Fixation Filter. In this paper we describe the test method used to determine the default values for the fixation filter and present the results from that test. We also discuss the collected results and deduct from those results the values deemed most suitable as default values for the fixation filter, which will be used within various research fields and by various users. This paper is a complement to the paper *The Tobii I-VT Fixation Filter - Algorithm description,* which also can be found on Tobii's website.

www.tobii.com

Contents

1. Background

In Tobii Studio 2.3 a new fixation filter was introduced in the software. The filter was an I-VT fixation filter [13] and for the users to be able to use it, it needed to be provided with default values. As Tobii Eye Trackers and Tobii Studio are used by a wide variety of users within different fields of research and different levels of knowledge about eye tracking, the default parameter values in Tobii Studio need to be good enough to work for most of the users.

Since the viewing patterns varry widely between different research fields as well as the characteristics of interest in these patterns, it is very difficult to determine default parameter values that are optimal for all fields of eye tracking research. When selecting the default parameter values for the Tobii I-VT fixation filter we had to make some choices regarding for which situations the settings should be as optimal as possible and do our testing based on that. Many of our users utilize our eye trackers for commercial testing of websites or advertisements, but a substantial part also uses them for different kinds of behavioral research within an academic context. Within academic research, one of the more challenging uses of eye tracking, when it comes to identifying fixations, is within reading research. The reason is that saccades between fixations are typically fairly short, while the duration of fixations are shorter as well compared to other fields of research. Therefore the I-VT filter should be able to work for reading studies as well as for other fields of research where the identification of fixations is less difficult.

In addition to the research fields being different, we also faced the challenge of finding default values that work for all our stationary eye trackers. This is because Tobii Studio is used for data analysis for our entire set of eye tracker models. Apart from the fact that the displays attached to our most commonly used eye trackers differ in size – the eye trackers also sample the data with different frequencies. Hence, the default parameter values should work equally well for all our models of stationary eye trackers, i.e. the classified fixations should be approximately the same when sampled with a 60Hz eye tracker as when using a 300Hz eye tracker if the same study was run on both.

2. Methodology

2.1. Fixation and saccade invocation task

Doing quantitative analysis for determining the accuracy of the fixation filter requires the fixations to be encoded in the stimuli, i.e. that it is known where the participants in the study are most likely to fixate. This means that a text, as is used in 'real' reading studies, could not be used as the fixations then would not be positioned in predictable locations. Hence, our fixation and saccade invoking task had to produce a fixation and saccade pattern similar to what is produced in a reading study without including any real reading on the participants' part [12]. In this study, this was done by using a black "jumping point" on a grey background. The size of the point (2.5mm in diameter) is approximately the size of a character written with font size 10, which corresponds to a visual angle of 0.2° at a distance of 71cm[1] from the stimuli plane.

As the stimuli are attempting to invoke gaze patterns similar to what occurs during reading, all stimuli points were presented on a straight line with the same y-coordinate. The y-coordinate was chosen so as to place 2/3 of the stimuli points within the optimal tracking area of the eye tracker, i.e. within a visual angle of 20° from the front center of the eye tracker unit and seen from a distance of 65cm from the eye tracker. Since the eye trackers used in the study had slightly different designs, this meant that the y-coordinate was not the same for all eye trackers.

Three times ten stimuli points were shown with a varied distance in between in order to eliminate predictability effects. The distance between two consecutive stimuli points corresponded to a saccade of either 1.6° or 3.3° (calculated at a distance of 71cm), which correspond to a saccade of 8 or 16 characters. 8 characters, according to Rayner [17], is a typical saccade length during reading while 16 character saccades are more uncommon [ibid.]. The display of ten stimuli points covered a visual angle of 22.2° as seen from a distance of 71cm. Each set of ten stimuli points had its own unique sequence of short and long jumps and was presented as a separate movie, in this paper called Video 1, Video 2 and Video 3 (see Figure 1).

[1]In this paper, 71cm is used as the distance between the screen and the participant when describing the stimuli in visual degrees. 71cm was also used by Morrison & Rayner [10] in the description of their stimuli.

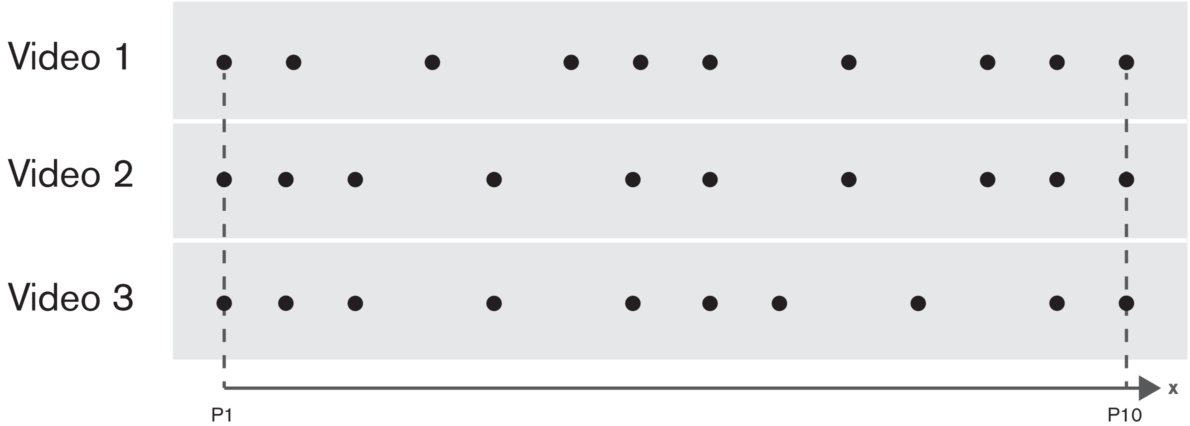


Figure 1. The sequence above illustrates where each stimuli point was positioned along the x-axis as seen from the first stimuli point (p1) to the last (p10).

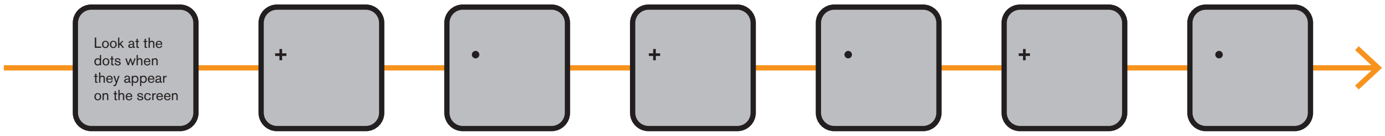


Figure 2. Distribution of stimuli items in a test.

Instead of letting the point disappear and the next point appear in a new position, a transition time was introduced where two consecutive points were shown at the same time for about 83ms. This overlap ensured that the participant's gaze did not wander when no points were shown and that the saccades between points were more likely to be direct and not introduce any intermediate gaze points due to searching for the new target. The duration of 83ms was selected due to the frame rate of the video encoder (24 fps). With a 24 fps frame rate, the duration could only be a multiple of 1/24≈ 41.67ms, which means that the transition is made during two frames in the video. 83ms is less than what is given as a typical duration of the saccadic latency [3], i.e. the time between a new stimulus point appearing and a saccade being initiated, which means that it could be assumed that any fixation initiated during this transition time could not be associated with the new stimulus point. In addition to the overlap time, each stimulus point was displayed for 500ms. This display time was selected to account for the remainder of the saccadic latency, the saccade between the previous and the new target and the average fixation time during reading [17].

3. Procedure

Participants were tested individually. Before the testing was initiated, the participants answered a few questions regarding age, vision aids, eye color and which eye is their dominant eye. The dominant eye was identified by using a simple hole-in-card test [5]. The participants were calibrated using a standard 9-point calibration where the point was set to move between the positions at a slightly higher speed than normal. This was to prime the participants for the fast moving stimuli points they would see during the actual test. The calibration points were red dots with a central black dot shown on a neutral gray background. An automated calibration procedure was used, which was initiated by the moderator.

As it is important that the fixation filter can perform accurate fixation classification under the circumstances eye tracking is commonly used, no chin rest or other means to fixate the head and eye position of the participants were applied.

In order to ensure that the time each stimulus point was displayed was consistent between eye trackers, participants and recordings, the presentation of the stimuli points was made as short movies. Before the first movie, written instructions were given on the display. Before the participants could proceed, the moderator ensured that the task had been understood. A fixation cross was shown for 800ms before the first movie and then again between the movies. This was to ensure that all participants looked at the same point before the actual stimuli points were displayed (see Figure 2).

The sessions when all three eye trackers were used lasted approximately 5 minutes where the data collection for each eye tracker took about 1.5 minutes each. The sessions where only the Tobii T60XL was used lasted about 3 minutes including introduction and data collection.

The illumination in the room in which the study was conducted was within the measured interval of 210 to 320 lux, which is normal light conditions in an office environment [6].

4. Participants

In our experience, the users of Tobii Eye Trackers and Tobii Studio often want to test all kinds of participants without excluding participants with glasses or other characteristics that might cause noisier data. Hence, it was important to ensure that the participants in this study represented both user groups where noise levels were low and groups where they are commonly higher. 24 participants were recruited and tested. Of these, 12 did not use any vision aids, 6 wore glasses and 6 used contact lenses. Ages were between 20 and 54. 16 had blue eyes while 8 had brown. Of the 24 participants 7 had a dominant left eye.

Table 1. Eye trackers included in the study.

Model name	Sampling frequency used in study (Hz)	Display resolution (pixels)	Accuracy[1] (°)	Firmware version	Eye tracking technique
T60XL	60	1920x1200	0.4	0.0.131 (Internal version)	Bright & Dark pupil tracking
T120	120	1280x1024	0.4	2.0.4	Bright & Dark pupil tracking
TX300	300	1920x1080	0.4	2.0.2	Dark pupil tracking

[1]*Accuracy under ideal conditions tested according to [16].*

5. Apparatus

As the fixation filter's default parameter values should work well for all stationary Tobii Eye Trackers, the testing required that eye trackers with different sampling frequencies and different designs were used. The eye trackers included in the study are presented in Table 1.

For the analysis, data export, and setting the fixation filter parameter values, a pre-release version of Tobii Studio 2.3 was used (0.23.120.0). Further analysis was done using Microsoft Excel 2007 in which VBA scripts were used to aggregate and present the data.

6. Data analysis

A fixation was considered to belong to a stimulus point if its center point was located within a radius of a 0.75° visual angle (as seen 71 cm from the stimuli plane) from the center of the stimulus point and the fixation was initiated after the previous point had disappeared and before the next point was displayed. The temporal restriction is based on the assumption that if the fixation is initiated before the previous point has disappeared it is caused by an overshoot when trying to fixate on the previous stimulus point. This is because the saccadic reaction time (SRT) of a healthy human is of longer duration than the time both points are shown simultaneously [11]. Hence, it is not physically possible to initiate a fixation on the current point before the previous point has disappeared. The radius of a 0.75° visual angle around the current stimulus point within which a fixation is deemed to belong to that point corresponds roughly to the average size of the foveola within which objects can be seen with high acuity [4].

Only two parameters in the Tobii I-VT fixation filter were tested in this study as the other parameter values could be deduced from literature within the topic of the physiology of the eye and from commonly used values in eye tracking research in general. A complete list of the parameter values used during testing can be found in Appendix I. The parameters which were evaluated in the current study were the *Window length* parameter in the *Velocity calculator* and the *Velocity threshold* in the *I-VT classifier*.

The values tested for the *Window length* parameter were 10ms and 20ms. These two values were selected based on them representing either two or three samples when applied to data from an eye tracker with a 120 Hz sampling frequency [12]. As both values only represent the gap between two samples when using a 60Hz sampling frequency, this means that no noise reduction is applied to data from an eye tracker that samples at a frequency of 60 Hz. By disabling the noise reduction functionality of the *Velocity calculator*, there is less risk of inadvertently smoothing out items in the lower frequency data that should not be removed [13].

The *Velocity threshold* parameter in the I-VT classifier was tested with the values 10, 20, 30, 40, 50, 60, 70 and 80°/s. These values were selected based on values found in literature where eye tracking and fixation analysis had been performed [1] [7] [9][13][15][16]. It should be noted that not all papers referenced here disclose which eye movement identification algorithm was used.

The ideal values for the *Window length* and *Velocity threshold* parameters for this test were determined to be when the values from the three different eye trackers corresponded. This success criterion was selected on the basis that it should be possible to compare fixation data recorded with eye trackers using different sampling frequencies. It was assumed that the participants' gaze behaviors remained the same independent of which eye tracker was used to collect the data.

6.1. Qualitative and quantitative scores

The purpose of a fixation filter is to correctly identify fixations within eye tracking data both in terms of the duration of the fixation and where the fixation is mapped on the stimuli. A good fixation filter is able to separate fixations even if they are located close together. It should also be able to cope with a reasonable level of noise without allowing the noise to split long fixations into many short ones. To mimic the gaze pattern of a reading study, we designed stimuli that showed points for a certain duration and with two different distances between them in order to invoke different lengths of saccades. To evaluate the efficiency of the Tobii I-VT filter we used some of the metrics discussed by Komogortsev et. al. [8]: Average number of fixations (ANF), Average Fixation Duration (AFD), Fixation Qualitative Score (FQlS) and Fixation Quantitative Score (FQnS). In addition to the metrics discussed by Komogortsev et. al. [ibid.], we also studied the data in more detail by calculating the metrics per point with the different saccade lengths preceding them.

6.1.1. Average Number of Fixations

In this report, the Average Number of Fixations (ANF) is calculated as a normalized value where the ideal value is 1 (see equation (1)).

$$\textit{Average Number of Fixations on stimuli points} = \frac{\textit{detected fixations}}{\textit{number of recordings} \times \textit{fixations encoded in the stimuli}} \quad (1)$$

The normalization of the number of fixations is done to simplify the understanding of the results. This is because the normalized value does not require the reader to know any details regarding the number of recordings included in the data set or the number of stimuli points presented. The value given by the metric is the average number of fixations for each fixation encoded in the stimuli, i.e. each stimulus point displayed.

6.1.2. Average Fixation Duration

The Average Fixation Duration (AFD) is simply the average time a fixation lasted. This is calculated by summing up the duration for all detected fixations and dividing them by the number of fixations detected (see equation (2)).

$$Average\ Fixation\ Duration = \frac{1}{N}\sum_{i=1}^{N} fixation\_duration_i \quad (2)$$

Due to the design of the stimuli, viewing the average without normalizing it provides more insight into the characteristics of the fixation filter than if the average was normalized. The ideal value would be 500 ms as this was how long each stimulus point was shown without it conflicting with any other stimuli points. However, this value is very rarely reached as the human visual system requires some reaction time between noticing the appearance of a new stimulus point and actually fixating on it. In this experiment, two consecutive stimuli points were visible simultaneously for 83 ms to allow for a direct transition between the previously visible point and the next without the introduction of any "stray" fixations in between. This transition time is not included in the 500 ms mentioned above.

6.1.3. Fixation Qualitative Score

According to Komogortsev et. al. [8]: "The Fixation Qualitative Score (FQlS) compares the spatial proximity of the classified eye fixation signal to the presented stimulus signal, therefore indicating the positional accuracy or error of the classified fixations[1]. The FQlS is calculated by summing up the distances between the detected fixations and their corresponding stimuli points and dividing it by the number of detected fixations (see equation (3)). The smaller the FQlS value is, the better the spatial accuracy of the classified fixations. However, this value is also affected by the accuracy of the eye tracker, i.e. if the eye tracker has an accuracy of 0.5°, the calculated gaze points will be within a radius of 0.5° visual angle from the actual gaze point. Hence, the FQlS score is likely to have a best possible value similar to the accuracy value of the eye tracker [8].

$$FQlS = \frac{1}{N}\sum_{i=1}^{N} fixation\_distance_i \quad (3)$$

[1] For a more detailed description of this metric, see Komogortsev et. al. [8].

The $fixation\_distance_i$ is calculated as the distance between the center of the fixation (x_c, y_c) and the center of the corresponding stimulus point (x_s, y_s) (see equation (4)).

$$fixation\_distance_i = \sqrt{(x_{s_i} - x_{c_i})^2 + (y_{s_i} - y_{c_i})^2} \quad (4)$$

6.1.4. Fixation Quantitative Score

The Fixation Quantitative Score (FQnS) calculates the sum of the samples belonging to fixations which can, by a set distance threshold, be deducted to belong to the displayed stimuli points during the time when the stimuli points were visibly divided by the total number of samples for which the stimuli points are visible. This can also be interpreted as the total time for which fixations are performed on the stimuli points divided by the total time the stimuli points were visible. The result is then multiplied by 100, which then provide a percentage of samples belonging to fixations detected when stimuli points were shown that were mapped to the displayed stimuli points (see equation (5)).

$$FQnS = 100 \times \frac{\sum fixation\_samples}{\sum stimuli\_point\_samples} \quad (5)$$

If the participants would be able to move their gaze between the stimuli points as soon as a new point became visible, the FQnS value should be 100. However, as the human visual system requires some reaction time and the characteristics of the stimuli design also caused some fixations to miss the stimuli points due to overshoots or undershoots, this value is not reachable in reality [8].

7. Results

As a wide variety of subjects were included as participants in this study, the data contains large variability both in terms of noise (see Figure 3) and, partly as a result of the noise, the calculated values for the different metrics. In the presentation of the scores, both the graphs of averages calculated for the various variables, as well as other graphs illustrating the findings, are included. In addition, the scores are often presented for subgroups of stimuli points (e.g. points with a short or a long jump preceding it or not including the first

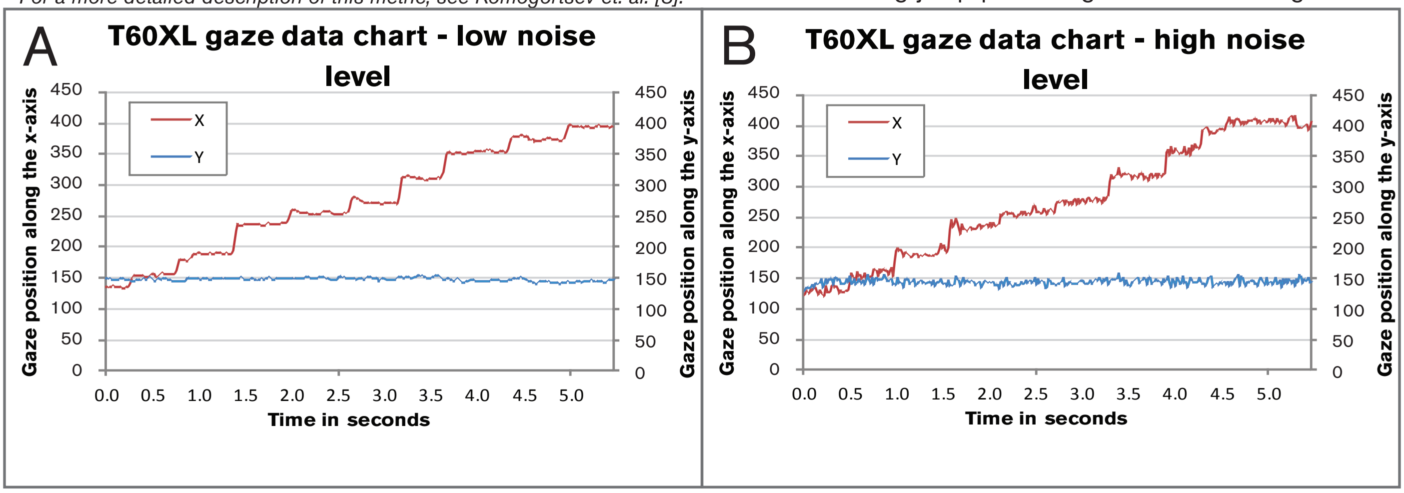


Figure 3. Charts showing typical, unfiltered eye tracking data from one sequence of stimuli points. Chart A) and B) show data captured using a T60 XL. All charts show data from the same sequence of stimuli points.

or last stimulus point in a video). A fixation is determined to belong to a stimulus point if the fixation starts after the previous stimulus point has disappeared (i.e. not during the transition time when two points are shown simultaneously) and the center of the fixation is within a radius of a 0.75° visual angle from the center of the stimuli point. Fixations that were initiated before the transition between one stimulus point to the next (i.e. when two points are shown simultaneously) are determined to belong to the point shown before the transition. This means that the fixations that are initiated during the transition time are ignored in the score calculations.

In the graphs illustrating the different scores presented in this chapter, each eye tracker and window length parameter value combination is represented by a separate line in the charts. However, for the T60XL eye tracker, the values for the window lengths, 10ms and 20ms, are identical due to the fact that 20ms only contains one sample when sampling at 60Hz. This means that velocity calculation is made between two consecutive samples both for the 10ms and 20ms values in the window length parameter. As a result, there will only be one line visible in each graph for the T60XL since the values for a 10ms and 20ms window are identical.

7.1. Average Number of Fixations (ANF)

When looking at the average number of fixations, it needs to be taken into account that not all fixations are made on the presented stimuli points. Hence, in Figure 4a all fixations in all recordings are used to calculate the ANF, while in Figure 4b, only the fixations that have been deducted to belong to a displayed stimulus point are included in the calculation of the metric. The discrepancy between the overall fixations and fixations on the stimuli points can be caused by various things such as stray fixations, errors made by the fixation classification, noise in the data (that causes the fixations to be positioned outside of the 0.75° visual angle radius around the stimulus point) etc. What is interesting to notice in both graphs is that the results from the different eye trackers, as well as for the different velocity windows, seem to converge between the velocity settings 20°/s to 40°/s even if the T60XL seems to have a higher number of overall fixations than the other eye trackers did. For velocity values over 40°/s, the data from the different eye trackers seems to diverge; the 300Hz data with a 10 ms velocity calculation window experiences a sharp rise in classified fixations and the other sets of data get a reduction in classified fixations. This might be due to more fixations being split into short fixations due to noise. In addition, these short fixations might be separated by a greater time difference than is specified in the *Max time between fixations* in the *Merge adjacent fixations* function so the short fixations are not merged into longer and fewer fixations.

7.2. Average Fixation Duration (AFD)

To compensate both for participants' potential slower reaction time when first seeing the moving stimuli points and possible inaccuracy of timing information when a video starts and stops playing, we removed the first and last stimuli points from the analysis of this measure. As can be seen in Figure 5a and Figure 5b, the difference is not very prominent even though there is a difference.

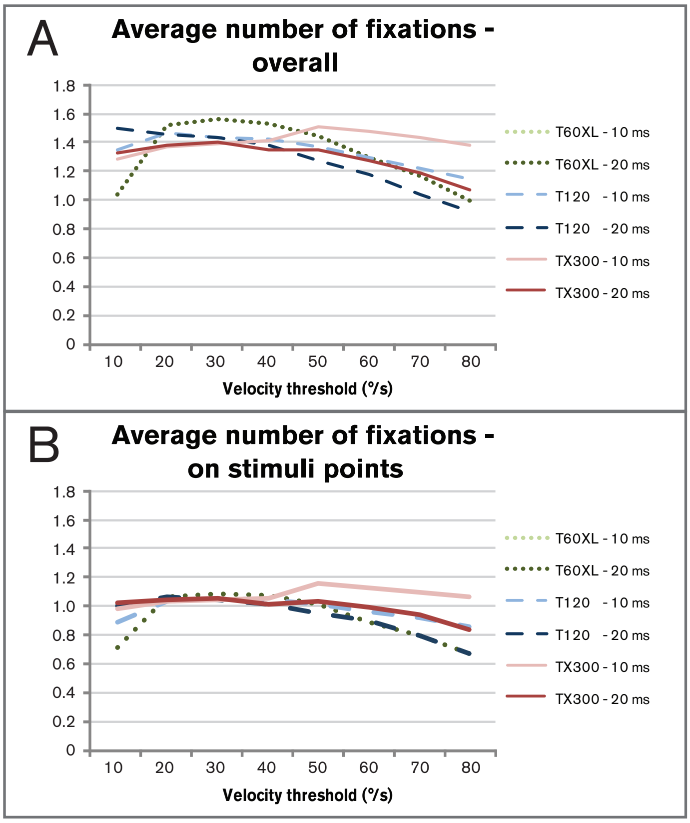


Figure 4. Aggregated data for 24 human subjects. A) Average number of fixations overall. B) Average number of fixations on stimuli points.

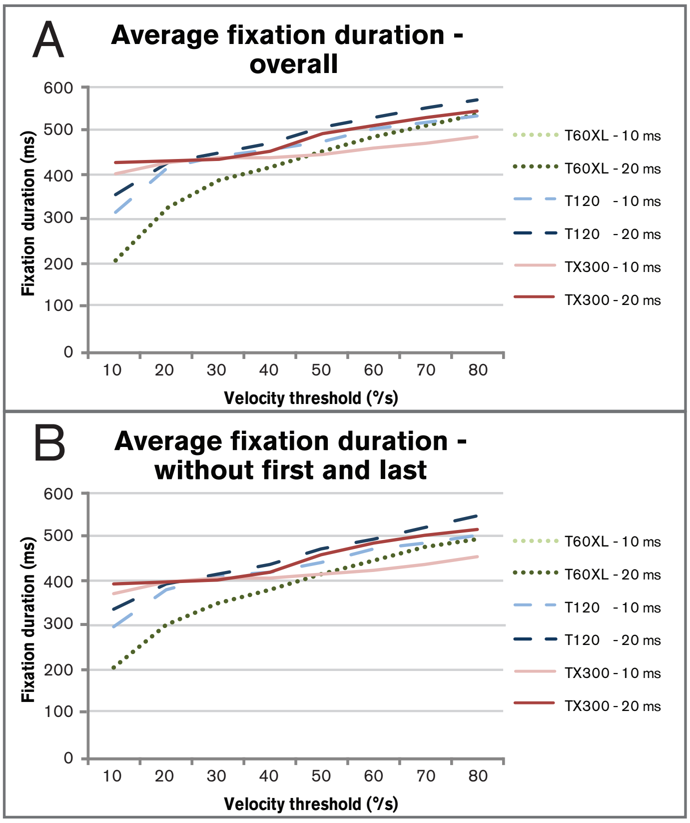


Figure 5. Aggregated data for 24 human subjects. A) Average duration overall. B) Average duration without the first and last stimuli point.

What might be more interesting is the difference between short and long jumps between stimuli points. The duration of fixations after short jumps (see Figure 6a) are substantially longer than after long jumps (see Figure 6b). This is probably due to more time being spent on compensating for too short or too long saccades, i.e. overshoots and undershoots, when trying to reach the stimulus point. This also causes some short overshoots or undershoot fixations being included in the measure, which further brings the average down.

In terms of the fixation filter parameter values there is a clear conversion at the velocity threshold values between 20°/s and 30°/s for both short and long jumps. For values over 40°/s the graphs diverge again. Interestingly, there is a clear divergence between the TX300 graphs for the window length values 10ms and 20ms when the velocity threshold value exceeds 40°/s.

As can be seen in Figure 7 where the fixation durations for the fixations are plotted in a histogram, the number of short fixations is greater when the velocity window parameter value is set to 10ms compared to when it's set to 20ms. In addition, there is a sharp rise in the number of fixations when the durations increase for the window parameter value 20ms. This is due to the low pass filtering characteristics of a larger window where the noise that divides long fixations into shorter fixations is removed.

In addition to illustrating the differences between the window length parameter values, the histogram in Figure 7 also highlights the problem of choosing a velocity parameter value which is too high: the threshold prevents short saccades

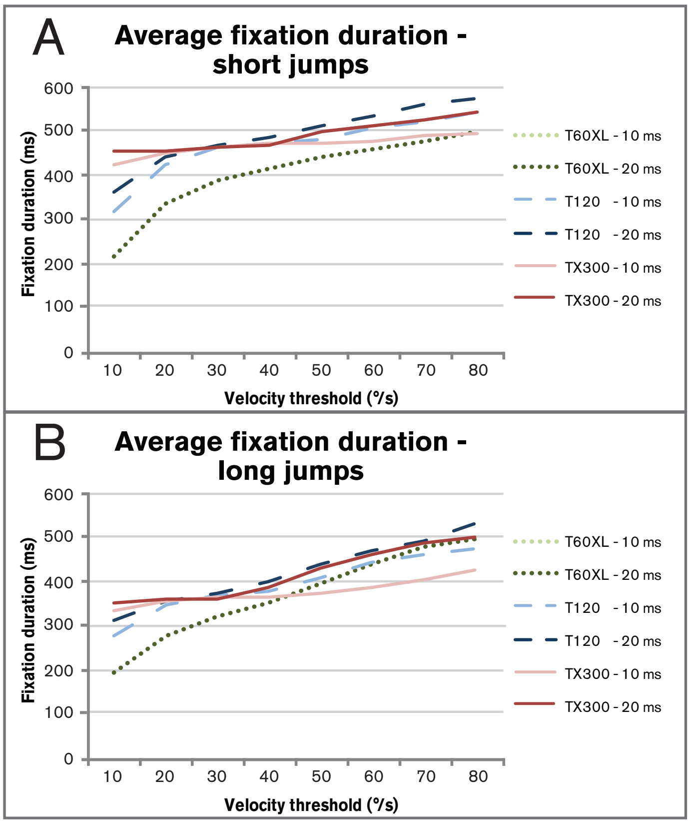


Figure 6. Aggregated data for 24 human subjects. A) Average duration for short jumps without the first and last stimuli points. B) Average duration for long jumps without the first and last stimuli points.

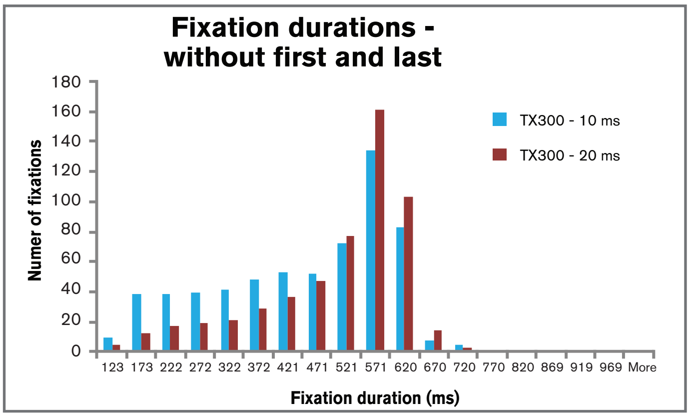


Figure 7. Fixation duration histogram without the first and last stimuli points for the TX300 with velocity window parameter values 10 and 20 ms and velocity parameter value of 60°/s.

to be detected, and therefore merges fixations together that should be separated. This means that there will be less short fixations than is actually the case and also many fixations with a significantly longer duration than is encoded in the stimuli, i.e. 500ms.

The same phenomenon is even more visible if looking at the chart showing the eye movements along the x-axis, the calculated velocity and the velocity threshold (see Figure 8) when the velocity threshold was set to 60°/s. When a too high value for the velocity threshold parameter value is selected, short saccades will be missed as a short saccade will result in a lower calculated velocity than a longer saccade. In Figure 8 this happens at two instances; while the orange line illustrates the eye movement, the red line shows the detected fixations. For the second and third fixation, as seen in Figure 8, it is clear that the detected fixations actually span over two separate fixations each. The yellow line below shows that the calculated velocity contains peaks between the actual fixations, but the peaks are too low to reach over the velocity threshold, which is illustrated by the black line.

Choosing a velocity threshold value that is too low can be equally dangerous, especially if the data is noisy. In Figure 6 the data from the different eye trackers also start diverging when approaching values of 20°/s or lower. The noise in the data starts to be detected as saccades and, hence, divides longer fixations into shorter fixations. The noise reduction

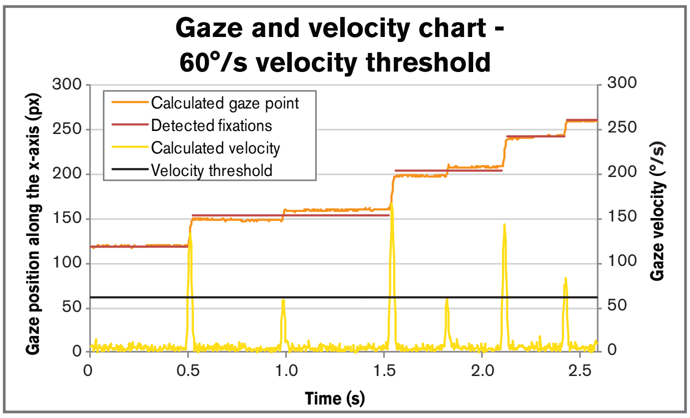


Figure 8. Chart showing the eye movement for one participant along the x-axis captured with a TX300 Eye Tracker, the calculated velocity (with a window parameter value of 20ms), the identified fixations and the set velocity threshold value of 60°/s.

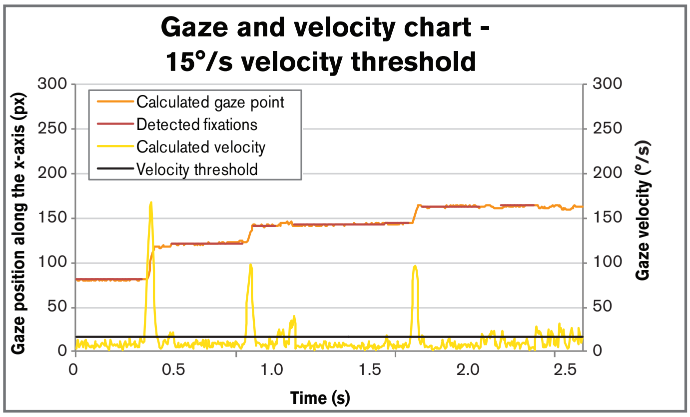


Figure 9. Long fixations split into shorter fixations because of a too low velocity threshold.

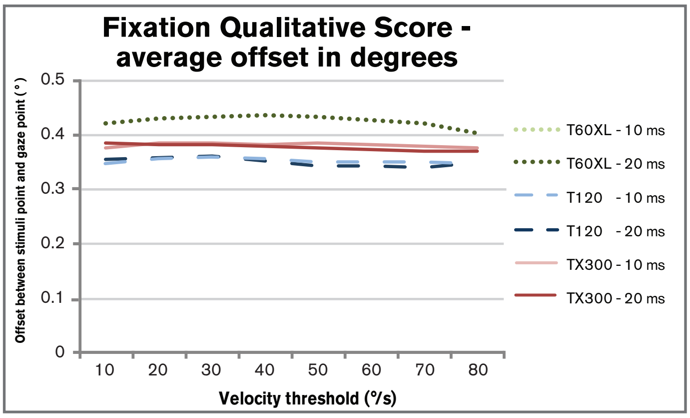


Figure 10. Long fixations split into shorter fixations because of a too low velocity threshold.

which applies to higher frequency data prevents this from happening more in data collected with a higher sampling frequency, which then causes the divergence between fixation durations from the different eye trackers.

As can be seen in the graph illustrating the calculated velocity in Figure 9, there are also peaks caused by noise and not by actual saccades. In the Tobii I-VT filter implementation a feature called *Merge fixations* is included. This feature merges fixations that are located close in time and space. This is done because some long fixations are divided into a number of short fixations due to noise in the data or short data losses. The Tobii I-VT filter's *Merge fixations* function has, in Figure 9, been turned off for the sake of illustrating the problem of selecting a too low velocity threshold value. When the *Merge fixations* function is turned off, fixations that are located close in space and time are not merged. In Figure 9, noise causes the velocity to rise above the threshold and creates some short fixations. In order to avoid classifying peaks caused by noise as ends or beginnings of fixations, the velocity threshold parameter value has to be selected so the peaks caused by noise do not reach or exceed the threshold value while at the same time allowing peaks caused by actual saccades to surpass the threshold value. When the data is very noisy or when the saccade lengths are short, finding such a value can be very difficult.

Based on the AFD score, the velocity threshold value should be somewhere between 20°/s and 40°/s for the fixation filter to classify the fixations consistently for all eye trackers included in the test.

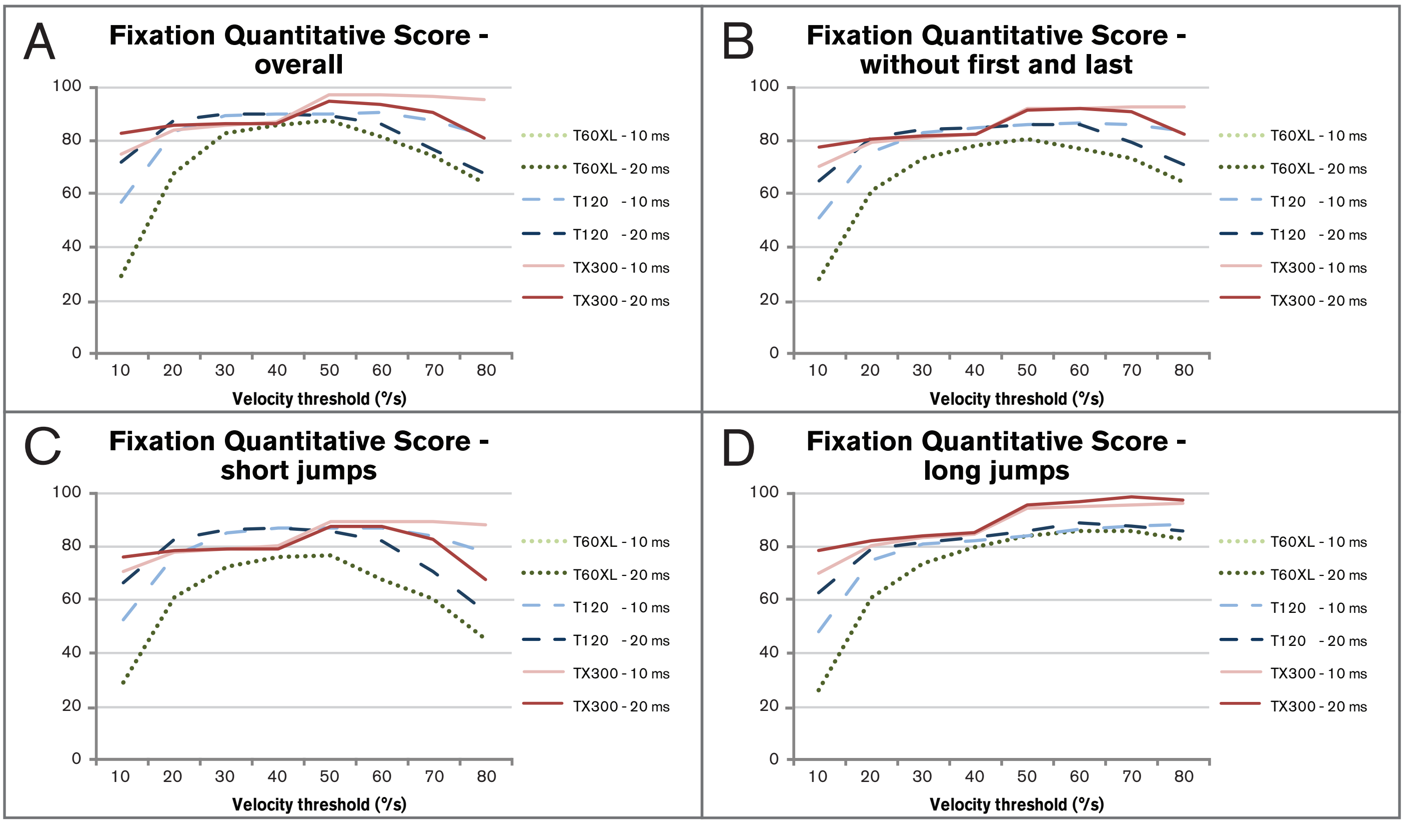


Figure 11. FQnS for A) all stimuli points, B) all stimuli points except for points at the first and last position of each set, C) stimuli points preceded by a short jump and D) stimuli points preceded by a long jump.

7.3. Fixation Qualitative Score (FQlS)

The FQlS shows the average offset between the stimulus point position and the detected fixations. To simplify the interpretation of this score, the distance is given in degrees of visual angle instead of actual distance. As the stimulus point positions are described as visual degrees seen from a distance of 71 cm from the display, the same distance was used for calculating the visual degrees between the stimulus point positions and the calculated fixation positions[1].

As can be seen in Figure 10, the velocity threshold parameter value seemed to have very little impact over the FQlS. The graphs for all eye trackers and window parameter values appear only to have changed marginally when the velocity threshold changed. The same is true for the window length parameter value.

7.4. Fixation Quantitative Score (FQnS)

The FQnS is a measure of the percentage of the total amount of samples classified as fixations that are corresponding to a stimulus point being shown at the same time. Also, the location of the fixation is taken into account and only samples belonging to fixations within proximity of a stimulus point is included in the score. As this is indirectly a measure of fixation duration, we have chosen to calculate the score not only for the total number of fixations, but also after excluding the first and last stimulus point in each stimulus point set. In addition, we have made the calculation for stimuli points with a short or long jump preceding it separately. For the FQnS for short and long jumps the last stimulus point in a stimulus point set is also excluded.

In all the charts displayed in Figure 11 the FQnS seems to converge for all eye trackers and window size parameter values when the velocity threshold is about 40°/s. This indicates that the fixation filter would identify fixations almost consistently for all eye trackers with this velocity threshold parameter value according to this score. However, the graphs starts to diverge significantly already by 50°/s which indicates that selecting 40°/s as a default parameter value in the filter would introduce a risk of introducing inconsistent classifications for different sampling frequencies and eye trackers if the data entered into the filter have just slightly different saccade amplitude characteristics. This can clearly be seen if looking at Figure 11c and Figure 11d where the stimuli points are preceded by different saccade amplitudes. With longer saccades, even higher velocity threshold parameter values result in acceptable FQnS and actually improves the outcome of the fixation classification slightly while the FQnS declines rapidly when the velocity threshold value rises for short saccades.

Table 2. Summary of the measured scores

Scores	Interval for witch the scores from the eye trackers correspond
ANF	20-40°/s
AFD	20-30°/s
FQlS	10-80°/s
FQnS	20-40°/s

8. Discussion

The parameter value testing of the Tobii I-VT fixation filter was done with very specific stimuli, which proved to be suitably chosen in terms of indicating the different influences the fixation filter settings as well as the stimuli characteristics have on the classification of fixations. For example, the saccade amplitude encoded in the stimuli helped illustrate the differences in the success rate of classifying fixations correctly depending on velocity threshold parameter values. Fixations preceded by longer saccades could be correctly identified with higher velocity threshold parameter values than fixations preceded by short saccades. This was indicated both by the FQnS as well as by looking at the velocity chart for individual recordings.

8.1. Selecting the default parameter values based on the current study

It should be kept in mind when examining the results of the testing that the aim of the study was to determine values that produced, if not exactly the same, at least as similar results as possible from all the included eye trackers and sampling rates. Taking into account the different scores and results presented in Table 2, the very highest value for the velocity threshold parameter that would provide the most consistent results for all eye trackers tested is 40°/s. However, as the fixation classifications according to the ANF score, AFD score and FQnS start to diverge for values of 40°/s and over for the eye trackers tested, it appears wise to choose a lower default value than that. By looking at the ANF scores, AFD scores and FQnSs the best possible value is about 30°/s as the scores for all eye trackers both seem to converge as well as stay somewhat stable between 20°/s and 40°/s.

Interestingly, the window length parameter value had only marginal impact on the scores when the velocity threshold values were between 20°/s and 40°/s. This is probably due to the *Merge adjacent fixations* function in the Tobii I-VT filter. Even if noise in the data splits some long fixations into shorter ones, this function manages to merge them together again. However, verifying that is beyond the scope of this study. Due to the slightly better performance for a window of 20ms for most scores outside the 20°/s to 40°/s scope, this value seems to be the preferred choice as the default value to use in the Tobii I-VT filter.

8.2. Limitations

Even though our ambition with this study was to identify a set of default values that are suitable for all the eye

[1]The numbers given in the technical specification for Tobii Eye Trackers regarding accuracy are calculated for a distance of 65 cm from the display. Hence, it is not possible to compare the values shown in Figure 10 directly with the accuracy values given in the technical specification without making some additional calculations.

trackers currently in our product range except for the Tobii Glasses, the optimal values for the fixation filter settings are dependent on the participants included in the study as well as what stimuli are used since longer saccades generate higher velocities than short saccades [2]. Our analysis in this paper is dependent on the assumption that the participants distributed their gaze according to the cues that were encoded in the stimuli. Hence, our conclusions are based on a comparison of the gaze data collected from the participants in the study against the “ideal” gaze patterns encoded in the stimuli.

The stimuli used in this study only triggered horizontal saccades, which means that the vertical components of eye movements were not included when determining the optimal values for the fixation filter.

Another assumption made in order to simplify the analysis is that the participants' gaze pattern is normally distributed and that averages can be used to draw conclusions. A visual inspection of the participants' gaze patterns did not reveal any outliers in need of removal from the data for this assumption to be valid, but no further investigations were made regarding the normal distribution of the data.

9. Conclusion

In this report we have tried to account for the process of identifying default values for the Tobii I-VT filter. This includes the reasoning behind the study design, testing of different parameter values and results of the testing. Our ambition has been to be as transparent as possible in order to allow our users to reuse the test methodology to test their own datasets if needed. However, the main purpose of the study was to identify filter settings that would not only provide the best fixation classifications possible, but also provide roughly the same results independent of which eye tracker was used. It is possible to tweak the filter settings so they provide better results for each eye tracker individually, but this would mean that our users must actively select the settings that are optimal for the eye tracker they are using. Since the fixation filter has a substantial impact on the results from an eye tracking study, selecting the wrong settings can have a dramatic impact on the conclusions drawn from the study. By selecting values that produced similar results independent of eye tracker and sampling frequency, we can assume that the fixation classification also will work well enough for all eye trackers and lead to the same conclusions even if eye trackers of different sampling frequencies were used to collect the data in the same study.

10. Bibliography

[1] Andrews, T. Idiosyncratic characteristics of saccadic eye movements when viewing different visual environments. Vision Research 39, 17 (1999), 2947-2953.

[2] Collewijn, H., Erkelens, C.J., and Steinman, R.M. Binocular co-ordination of human vertical saccadic eye movements. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1190821.

[3] Drewes, J. and VanRullen, R. This Is the Rhythm of Your Eyes: The Phase of Ongoing Electroencephalogram Oscillations Modulates Saccadic Reaction Time. Journal of Neuroscience 31, 12 (2011), 4698-4708.

[4] Duchowski, A. Eye tracking methodology : theory and practice. Springer, London, 2007.

[5] Durand, A.C. and Gould, G.M. A Method of Determining Ocular Dominance. The Journal of the American Medical Association 55, 5 (1910), 369-370.

[6] Galasiu, A. and Veitch, J. Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review. Energy and Buildings 38, 7 (2006), 728-742.

[7] Komogortsev, O.V., Gobert, D.V., and Dai, Z. Classification Algorithm for Saccadic Oculomotor Behavior. Dept. of Computer Science, Texas State University-San Marcos, 2010.

[8] Komogortsev, O.V., Gobert, D.V., Jayarathna, S., Do Hyong Koh, and Gowda, S.M. Standardization of Automated Analyses of Oculomotor Fixation and Saccadic Behaviors. IEEE Transactions on Biomedical Engineering 57, 11 (2010), 2635-2645.

[9] Leigh, R. The neurology of eye movements. Oxford University Press, New York, 2006.

[10] Morrison, R.E. and Rayner, K. Saccade size in reading depends upon character spaces and not visual angle. Perception & Psychophysics 30, 4 (1981), 395-396.

[11] Munoz, D.P., Broughton, J.R., Goldring, J.E., and Armstrong, I.T. Age-related performance of human subjects on saccadic eye movement tasks. Experimental Brain Research 121, 4 (1998), 391-400.

[12] Olsen, A., Matos, R. Identifying parameter values for an I-VT fixation filter suitable for handling data sampled with various sampling frequencies. Proceedings of the Symposium on Eye Tracking Research and Applications, ETRA '12, (2012), 317-320

[13] Olsen, A. The Tobii I-VT Fixation Filter - Algorithm description, Retrieved from http://www.tobii.com/eye-tracking-research/global/library/white-papers/the-tobii-i-vt-fixation-filter/, (2012)

[14] Over, E.A.B., Hooge, I.T.C., Vlaskamp, B.N.S., and Erkelens, C.J. Coarse-to-fine eye movement strategy in visual search. Vision Research 47, 17 (2007), 2272-2280.

[15] Radach, R., Huestegge, L., and Reilly, R. The role of global top-down factors in local eye-movement control in reading. Psychological Research 72, 6 (2008), 675-688.

[16] Rayner, K., Li, X., Williams, C., Cave, K., and Well, A. Eye movements during information processing tasks: Individual differences and cultural effects. Vision Research 47, 21 (2007), 2714-2726.

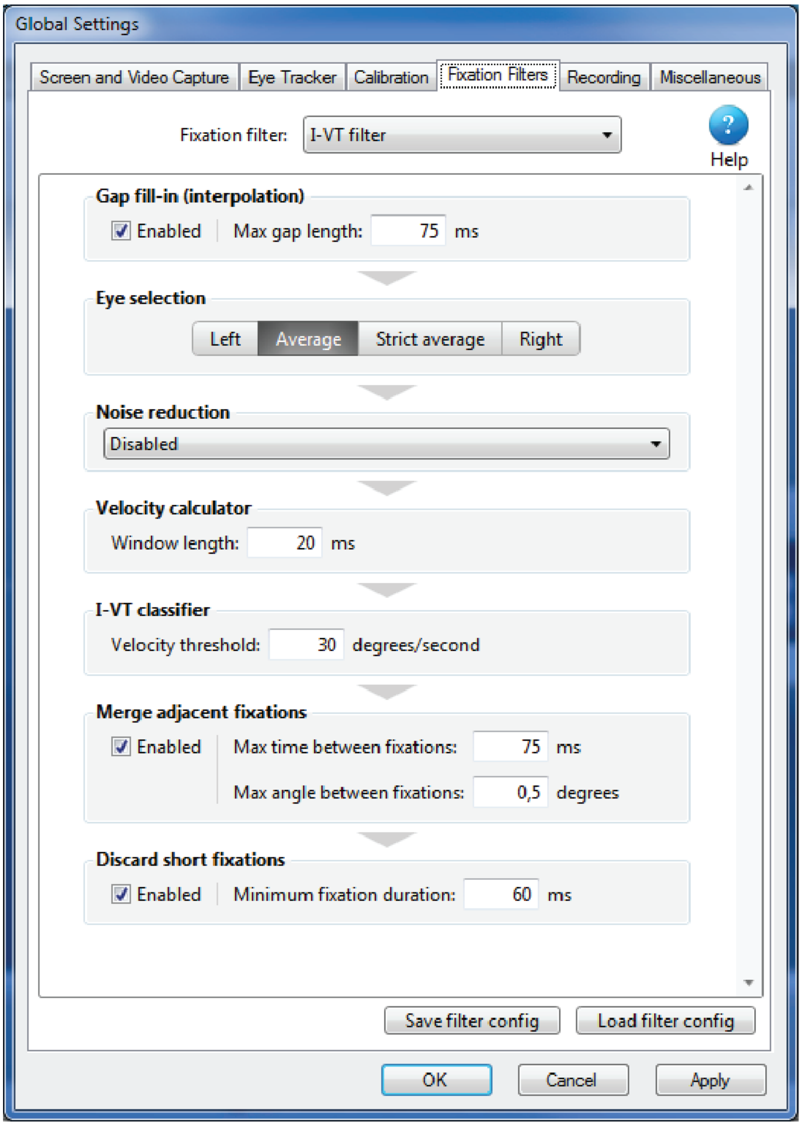
[17] Rayner, K. Eye movements in reading and information processing: 20 years of research. Psychological Bulletin 124, 3 (1998), 372-422.

[18] Tobii Technology AB. Accuracy and precision test method for remote eye trackers - Test Specification Version: 2.1. 2011. http://www.tobii.com/Global/Analysis/Training/Metrics/Tobii_Test_Specifications_Accuracy_and_PrecisionTestMethod_version%202_1_1_.pdf.

Appendix 1

Function parameter values used in Tobii Studio during testing

Function	Function parameters	Function parameter values
Gap fill-in (interpolation)	Max gap length	75 ms
Eye Selection	N/A	Average
Noise reduction	N/A	Disabled
Merge adjacent fixations	Max time between fixations	75 ms
	Max angle between fixations	0.5°
Discard short fixations	Minimum fixation duration	60 ms



Tobii Support contact

SWEDEN/GLOBAL
+46 8 522 950 10 Phone
support@tobii.com
www.tobii.com
Support hours: 9 am - 5 pm
(Central European Time, GMT+1)

GERMANY
+49 69 2475 034-27 Phone
support@tobii.com
www.tobii.com
Support hours: 9 am - 5 pm
(Central European Time, GMT+1)

NORTH AMERICA
+1 703 738 1320 Phone
support.us@tobii.com
www.tobii.com
Support hours: 8 am - 5 pm
(US Eastern Standard Time, GMT-6)

JAPAN
+81-3-5793-3316 Phone
support.jp@tobii.com
www.tobii.co.jp
Support hours: 9 am - 5.30 pm
(GMT+9)

SWEDEN/GLOBAL
Tobii Technology AB
Karlsrovägen 2D
Box 743
S-182 17 Danderyd
Sweden
+46 8 663 69 90 Phone
+46 8 30 14 00 Fax
sales@tobii.com

CENTRAL EUROPE
Tobii Technology GmbH
Niedenau 45
D-60325 Frankfurt am Main
Germany
+49 69 24 75 03 40 Phone
+49 69 24 75 03 429 Fax
sales.de@tobii.com

NORTH AMERICA
Tobii Technology, Inc.
510 N. Washington Street
Suite 200 - Falls Church,
VA 22046 - USA
+1-703-738-1300 Phone
+1-888-898-6244 Phone
+1-703-738-1313 Fax
sales.us@tobii.com

JAPAN
Tobii Technology, Ltd.
3-4-13 Takanawa, Minato-ku
Tokyo 108-0074
Japan
+81-3-5793-3316 Phone
+81-3-5793-3317 Fax
sales.jp@tobii.com

CHINA
Tobii Electronics Technology
Suzhou Co., Ltd
No. 678, Fengting Avenue
Land Industrial Park
Weiting, Suzhou
Post code: 215122
China
+86 13585980539 Phone
sales.cn@tobii.com

tobii
www.tobii.com