# A Comparison of post-saccadic oscillations in European-Born and China-Born British University Undergraduates.

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## Abstract

Previous research has revealed that people from different genetic, racial, biological, and/or cultural backgrounds may display fundamental differences in eye-tracking behavior. These differences may have a cognitive origin or they may be associated with physiological oculomotor response. In this paper we look at one of the physiological aspects of eye movements known as post-saccadic oscillations and we show that these type of eye movements could be very different between two different populations. As a case study, we compare the post-saccadic oscillations recorded by a video-based eye tracker between two groups of participants: European-born and Chinese-born British students. We recorded eye movements from a group of 42 Caucasians defined as White British or White Europeans and 52 Chinese-born participants all with ages ranging from 18 to 36 during a prosaccade task. The post-saccadic oscillations were extracted from the gaze data which was compared between the two groups in terms of their first overshoot and undershoot. The result shows that the shape of the post-saccadic oscillations varies significantly between the two groups which may indicate a difference between the damping characteristics of the ocular muscles. We further show that differences in the post-saccadic oscillations could influence the oculomotor statistics such as saccade duration. We conclude that genetic, racial, biological, and/or cultural differences could affect the quality of the eye movement data recorded by an eye tracker and must be considered when studying eye movements and oculomotor fixation and saccadic behaviors.

## Introduction

With the emergence of 'cultural neuroscience' the nature vs. nurture debate has never been more pertinent. Predominantly it is thought that culture leads to differences in top-down executive functions [1, 2]. As a result of the amalgamation of culture and biology [3, 4], humans exhibit differences in morphology and behavior, such as in eye movement. Previous research has found a number of differences between different cultures in terms of eye movements. For example, it has been observed that there are differences between groups when thinking about the answers to questions; Canadians and Trinidadians tended to look up, whereas Japanese looked down more frequently [5].

Eastern Asian participants were observed to deploy a central fixation strategy across different visual categories [6]. In general, visual attention research has identified East-West differences associated with holistic versus analytic perception and reasoning strategies [7–9]. Westerners tend to fixate more often, more quickly and more accurately on focal objects [9–12] compared to Easterners. In contrast, Easterners allocate attention more globally and broadly in visual processing compared to Westerners [9,10]. Easterners are found to make more numerous [13,14] and shorter duration [13] fixations, and consume longer searching time in visual searching tasks [14]. Whether these differences between different groups are due to nature (biology, genetics, race) or nurture (culture) is still debated.

Despite the above, disputes exist about the cultural influence in visual attention. Remarkably, nurture has been reported to be more influential in shaping human oculomotor behavior than nature [3]. However, in the work of *Rayner et al.* [15], no difference was found in scene perception between Eastern and Western Viewers. Differences in cognition and perceptual processes have been observed by eye movement research on Chinese and Caucasian participants (e.g. [12]). For example, effects of culture on the different aspects of visual attention have been observed for fixation duration, number of fixations, and saccades [12,16]. Also, more recently, Knox and Wolohan (2014) suggest a distinction in oculomotor phenotype between Chinese and Caucasian as their British-Chinese participants performed analogously to Chinese participants from China [2]. This, therefore, suggests that environmental factors cannot be the only reason for eye movement differences.

Nystrom, Hooge, and Holmqvist (2013) compared the motion of the pupil center and the eyeball (measured through the center of limbus) in a video based eye-tracker and observed that the post-saccadic oscillations (PSO) of the pupil do not necessarily match the oscillations of the eyeball [17]. They later showed how this can affect the pupil and corneal reflection signals measured by the eye tracker [18]. Their results indicate that more knowledge about PSOs is essential to fully understand the underlying cause of this phenomenon and to compare the findings obtained from video-based eye trackers with other eye tracking technologies. They suggested that while the eye tracking technique could have a significant affect on the measurement of the post-saccadic oscillations, PSOs may also differ between populations because they are related to the elastic properties of the iris, which would vary across different populations. Other studies showed the effect of pupil size and saccade peak velocity (and saccade amplitude accordingly) on the shape of the PSO signals [19,20]. Mardanbegi et al. (2017) observed an aging effect on PSO; increased PSO was linearly associated with age [21]. This result clearly demonstrates that iris elasticity is affected by aging which may suggest that PSO differences are a result of structural changes in the eye. However, could differences in PSO be observed between age-matched cross cultural, cross racial, or cross genetic populations?

In this study, we looked at the eye movements of two groups of participants (European-Born and China-Born British University Undergraduates) recorded in a video watching experiment. We extracted the post-saccadic oscillations from the eye tracking data and compared that across the two groups. The results show that the shape of the PSOs were significantly different between the two groups. The differences in PSO are important to consider when studying eye movements of different groups of people as it may have methodological implications for measurement of eye movement metrics. Further, our results may enable us to better understand the origin of the PSOs and whether PSO differences are due to structural iris elasticity or socio-cultural influential factors.

# Materials and methods 60

The eye tracking data was recorded in a video watching experiment where participants 61
viewed three videos which were each displayed for 40 seconds. The videos were (1) 62
Coronation of the Queen Elizabeth II, (2) Gordon Brown and family leaving Downing 63
Street after losing the general election in 2010, and (3) Neil Armstrong landing on the 64
moon. Participants were given a general introduction before each video about the 65
content of that video, but they were informed that they could freely view each video on 66
the first viewing. On the second and third viewing the participants were asked 67
questions designed to encourage visual search of each video. These video watching tasks 68
enabled us to obtain PSO signals for a wide range of saccadic eye movements with 69
different amplitudes collected from naturalistic viewing conditions more equivalent to 70
that in the real world. 71

## 0.1 Participants and apparatus 72

Our dataset included 94 participants: 42 European-born (Caucasians) students with 73
ages ranging from 18 to 36 (mean=21.0, SD:3.46)(9 male and 33 female), and 52 74
China-born (Chinese) students with ages ranging from 19 to 36 (mean=23.77, 75
SD:2.64)(25 male and 27 female). 76

All participants were undergraduate students recruited from a British university. 77
Written informed consent was obtained and the study was approved by Lancaster 78
University ethics committee and also the National Research Ethics Service (Health 79
Research Authority (HRA), 11/NW/0723). All of the Chinese participants were born 80
and raised in China and had moved to UK to undertake their undergraduate studies. 81
Caucasian participants (except four who where born in mainland Europe) were born 82
and raised in the UK and were all attending the same British university at the time of 83
testing. 84

Potential participants were made aware prior to the study that the study involved 85
eye movement measurement. Participants were asked to report any related medical 86
history. None of the participants were using any medications. 87

A fixed-head setup using an Eyelink 1000 eye tracking system (SR Research Ltd., 88
Ontario, Canada) was used to record participants' dominant eye (determined using the 89
Miles test [22] and tracked accordingly) at 500 Hz. A chin-rest with a forehead support 90
was used to help the subjects keep their head still during the experiment. Participants 91
were seated 55 cm away from a 24-inch Dell monitor (with the resolution of $1024 \times 768$ 92
pixels and refresh rate of 60 Hz) during the data collection. Prior to the experiment, the 93
camera was moved horizontally on the table to ensure that the camera was directly 94
facing the participants' tracked eye and the eye appeared in the center of the eye image 95
for each participant. A single user calibration with 9 points was performed prior to the 96
experiment. The result of the calibration was assessed by doing a validation test using 9 97
points right after the calibration. The calibration was repeated when the result of the 98
validation reported by the eye tracker was poor. 99

## 0.2 Procedure and Data collection 100

In the video watching experiment, the participants viewed three videos which were each 101
displayed for 40 seconds. The videos were (1) Coronation of the Queen Elizabeth II, (2) 102
Gordon Brown and family leaving Downing Street after losing the general election in 103
2010, and (3) Neil Armstrong landing on the moon.Participants were given a general 104
introduction before each video about the content of that video. Each participant 105
performed a free viewing task followed by two more instructed tasks in which they were 106
asked to find answers to questions designed to direct the top-down control of eye gaze 107

**Table 1. General oculomotor statistics for the data collected from the two groups.**

|  | $err$ | $N_{sac}$ | $N_{fix}$ | $dur_{fix}$ |
|---|---|---|---|---|
| Caucasians | 0.42°(SD=0.21) | 860.5(SD=161.1) | 971.5(SD=170.7) | 377.1 ms(SD=363.1) |
| Chinese | 0.48°(SD=0.14) | 788.1(SD=147.2) | 927.2(SD=170.5) | 377.7 ms(SD=367.4) |

Values shown inside parenthesis are the standard deviations. $err$: mean of the average error, $N_{sac}$: average number of saccades per subject ,$N_{fix}$: average number of fixations per subject, $dur_{fix}$: mean of the fixation duration.

(e.g. Question 1 of Video 3 was "How many bald men are in the room?") and to encourage visual search of each video. The two questions for each video were the same for all participants. The eye movements were collected from 9 video trials per participant. Each video lasted 40 seconds. The eye tracking data provided us with a wide range of saccadic eye movements from which we could extract the PSO signals.

## Data Pre-Processing

Saccade detection was done in the Eyelink tracking software with velocity and acceleration thresholds of 30°/s and 8000°/s2, respectively. We filtered those saccades that had a duration larger than 200 ms or a peak velocity of larger than 500 deg/sec which were considered as outliers. We also filtered those with amplitude larger than 20 deg or smaller than 1.5 deg because we didn't want to include microsaccades or unexpected large saccades in our PSO analysis. We used the PSOVIS software [23] to extract and align the PSO signals from the eye movement data. The PSOVIS software made it possible to include, align, and compare all saccades in the analysis regardless of their saccade amplitude and direction.

The PSO signals are represented by $PSO = S(t)$ where t is measured relative to the time where the first critical point of the saccade happens after the maximum velocity and $S$ is the gaze position relative to the position of the next fixation. For the majority of the signals, $t = 0$ is where the first bump of the under-damped signal happens. The PSOVIS software aligns all the signals temporally at $t = 0$, and spatially at $pso = 0$ at which the oscillation ends (next fixation). Multiple PSOs can be lumped into one signal by taking the median of all values at each time step ( $\underset{i=1,2,...,n}{\mathrm{median}} \{S(t)_i\}$ where $n$ is the number of signals).

## Results

As an overall comparison of the data quality between the two groups, we extracted the details of the validation step stored as EDF files generated by the EyeLink tracker and compared the calibration quality between the two groups. The mean of the average error ($err$) measured in degrees of visual angle is shown in Table 1. Some other general oculomotor measures such as the mean of the fixation count ($N_{fix}$) and saccade count ($N_{sac}$) per subject and the mean of the fixation duration ($dur_{fix}$) are presented in Table 1 for both groups. The number of saccades was counted after the filtering process described above. In total 25072 saccades were obtained from the Caucasian group and 29189 from the Chinese group. We found no statistical differences between these measures across the groups.

Figure 1 shows the distribution of various oculomotor measures indicating that those measurements except for pupil size were relatively similar across the two groups of participants. We therefore consider the pupil size as an independent factor later in our analysis.
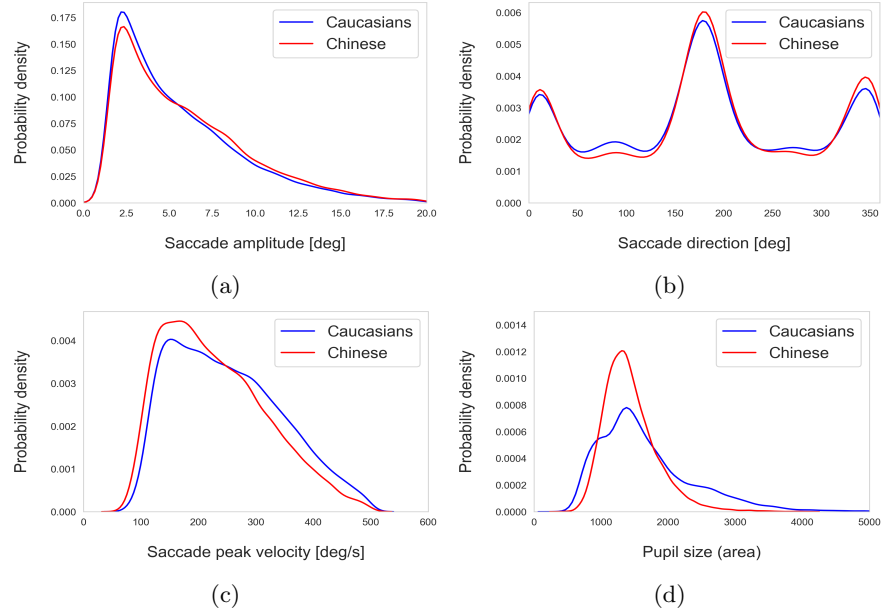
**Fig 1. Kernel density of various measurements across the two groups.**

Figure 2 shows the PSO signals for 6 different ranges of saccade amplitude from 0 to 146
20°. To avoid crowding the figure, we only show the median signal within each range 147
instead of individual signals. PSO signals are colored differently for different saccade 148
amplitudes. Each median signal in the figure represents the median of all PSOs of an 149
individual subject that belong to saccades with amplitudes within a certain range. In 150
order to compare the signals between our two groups we measured two features from 151
each signal. The first feature is the first overshoot peak of the signals that happens at 152
$t = 0$ ($S(0)$). The second feature was the PSO value at $t = 10$ ($S(10)$) where the first 153
undershoot of the majority of the PSOs happen. 154

A typical approach for analyzing data of this type (several observations from each 155
subject and several subjects) is to fit a Linear Mixed Model (LMM) [24]. Previous 156
research [21] has considered the difference between groups using a single point of the 157
PSO signal ($t = 0$). Whilst this is informative, we are interested in the joint difference 158
between the PSO at $t = 0$ and at $t = 10$. Thus, for each saccade, we have a bivariate 159
response variable. In building our bivariate model we considered the variables: pupil 160
size, age, gender, saccade amplitude and group. Note that because of the main sequence 161
relationship between saccade peak velocity and amplitude, any possible effect of peak 162
velocity on the PSO is indirectly exerted via saccade amplitude. The most (statistically) 163
appropriate mixed model is given in equation 1 where log(saccade PSO amplitude) for 164
person $j$ is a function of square root of pupil size (P), logarithm of the saccade 165
amplitude (A) and group. The $u_j$ term is the additional term allowing a different 166
intercept for each person. Interestingly age is not significant in our analysis, this is 167
likely due to the lack of variability in age, with 90% of our saccades being taken from 168
participants 18-25. 169

$$
\left( \begin{array}{c} \sqrt{S(0)_j} \\ \sqrt{S(10)_j} \end{array} \right) = \left( \begin{array}{c} \beta_1^0 \\ \beta_1^{10} \end{array} \right) + \left( \begin{array}{c} \beta_2^0 \\ \beta_2^{10} \end{array} \right) \sqrt{P} + \left( \begin{array}{c} \beta_3^0 \\ \beta_3^{10} \end{array} \right) \log A + \left( \begin{array}{c} \beta_4^0 \\ \beta_4^{10} \end{array} \right) I_{Chinese} + u_j.
$$
(1)

The values of the fitted mixed effects model are given in Table 2 and Fig. 3. This 170
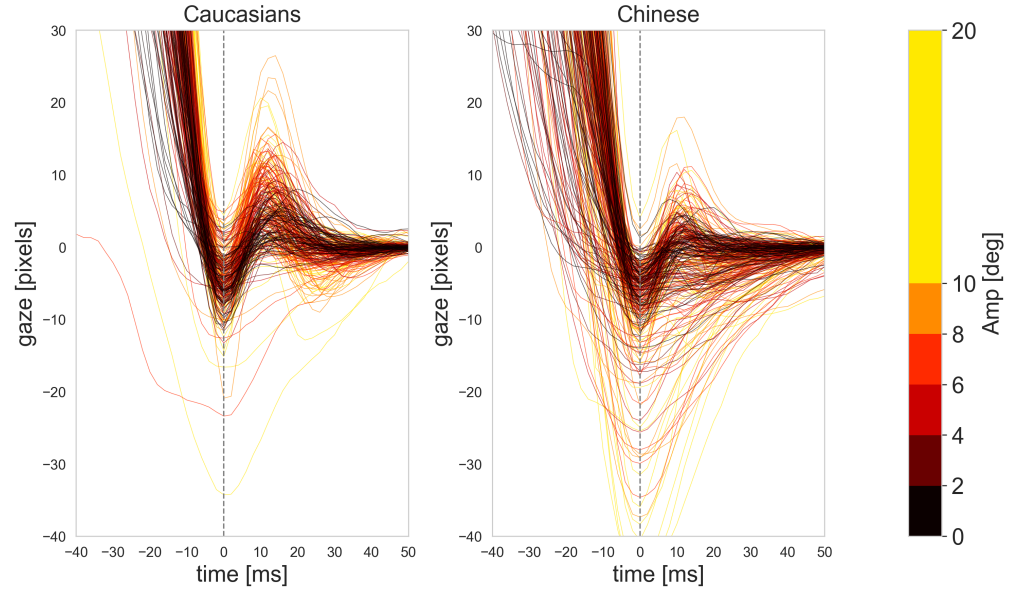
**Fig 2. The median PSO signals of all the saccades for Caucasians and Chinese groups.**
Each signal shows the median of all recorded signals per subject inside each range of peak velocity. Colors represent the peak velocity for each PSO.

**Table 2.** Results of the bivariate linear mixed model analysis. Each of the variables in our final model alongside its estimate and 95% confidence interval.

|  | Estimate (t=0) | CI 2.5% | CI 97.5% | Estimate (t=10) | CI 2.5% | CI 97.5% |
|---|---|---|---|---|---|---|
| Intercept | 10.727 | 10.678 | 10.777 | 8.912 | 8.863 | 8.962 |
| $\sqrt{P}$ | -0.0053 | -0.0059 | -0.0046 | -0.0007 | -0.0012 | -0.0001 |
| $\log A$ | -0.0166 | -0.0207 | -0.0125 | 0.1019 | 0.0962 | 0.1077 |
| $I_{Chinese}$ | -0.0877 | -0.1437 | -0.0318 | -0.2802 | -0.2875 | -0.2729 |

demonstrates that the PSO amplitude at $t = 0$ for a typical person in the Chinese group is 0.0877 times lower than that of a typical person in the Caucasian group. The effect is even more pronounced for the PSO amplitude at $t = 10$ where a typical person in the Chinese group is -0.2802 times lower. Recall this is on the square root scale.

Interestingly we also see that the saccade amplitude has a negative effect at $t = 0$ and a positive effect at $t = 10$. This is expected as the amplitude of the saccade affects the depth at $t = 0$ and the height at $t = 10$.

# Further investigations

Because the groups were not balanced in terms of gender, it may be that the difference in the PSOs of the two groups are caused by the difference in the number of female participants in the Chinese group. Gender was balanced in the Chinese group where 51.92% of the population were male and 48.08% female. We further looked at the effect of gender on the PSO signals. We also investigated whether wearing glasses could affect the size of the PSO signals. Horizontal and vertical saccades were also compared in terms of their PSO.
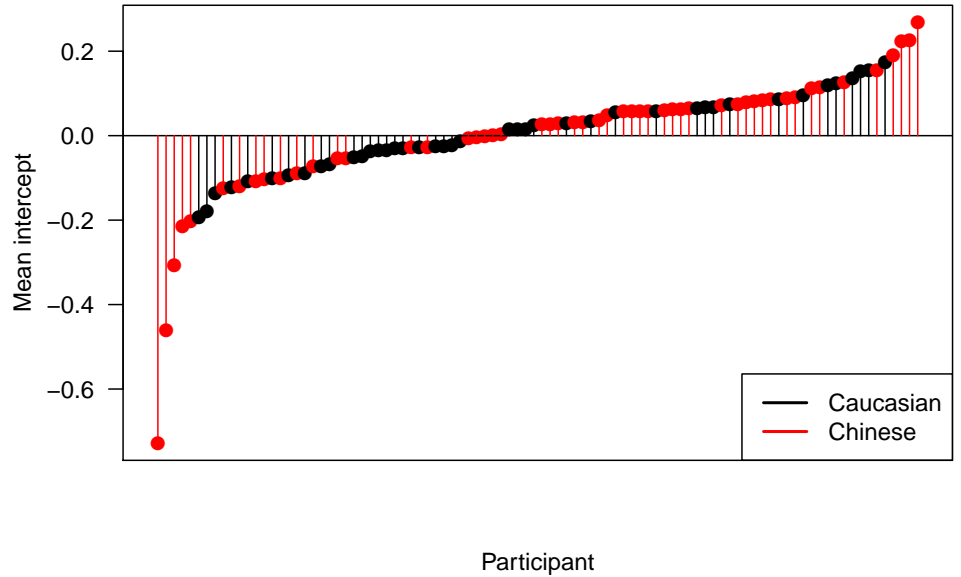
**Fig 3.** Mean random effect intercepts per participant accompanying the estimates of the fixed effects from Table 2.

## 0.3    Effect of Gender

We divided the Chinese group into two subgroups (male and female) and compared the PSO signals between these groups. Figure 4 shows the PSO signals of the 27 male and 25 female subjects in the Chinese group for different ranges of saccade peak velocities. The results show that the same pattern with very high under-damped oscillations for higher ranges of peak velocities are visible in both genders and it unlikely that the difference between the Caucasians and Chinese groups is coming from the gender differences.

## 0.4    Effect of saccade direction

While the distribution of the saccade direction was the same in the Caucasians and Chinese groups (as seen in Figure 1), vertical and horizontal saccades were compared in terms of PSO and we found no significant difference between the PSO signals of the vertical and horizontal saccades in either of the groups.

## 0.5    Effect of wearing glasses

In our study, we didn't record information about whether subjects were wearing glasses. However, before each recording, participants were asked to remove their glasses if possible as it aids the calibration process. Wearing glasses may change the appearance of the pupil in the eye image and change the shape of the oscillations of pupil center (and the glint) measured by the tracker. However, in our study, PSO signals were not directly extracted from the pupil center instead they were extracted from the gaze data. In this case, wearing glasses should not have a significant effect on the amplitude of the PSO, because the total amplitude of the saccade (obtained from the gaze data) will be
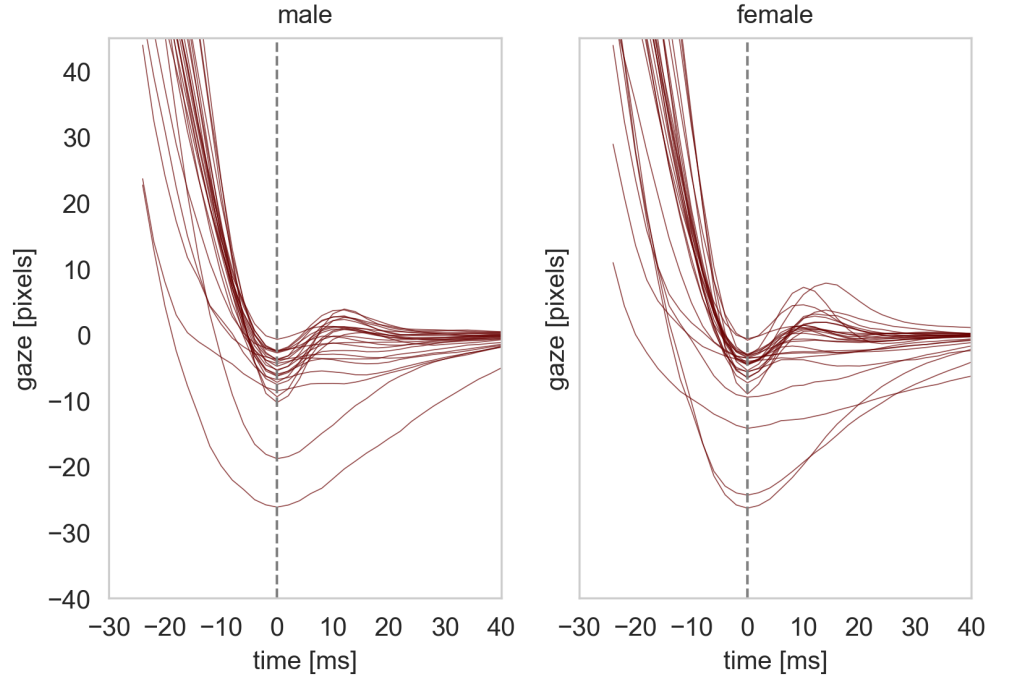
**Fig 4. The median PSO signals of male and female participants of the Chinese group.**

the same with and without glasses when the eye moves between two arbitrary points (A   208
and B). We further tested this on a person wearing thick glasses (SPH=-1.75,   209
CYL=-4.25 and AXIS=180) performing a pro-saccade task with and without glasses.   210
We found no significant differences between the size and the shape of the PSO signals of   211
the two conditions (50 signals were recorded per condition).   212

## Discussion   213

The results of our study either imply that Chinese and Caucasian iris elasticity is   214
structurally different from birth (i.e. a result of biology, race, or genetics), or that there   215
are socio-cultural factors which can affect PSO. Knox and Wolohan, 2014, suggest a   216
distinction in oculomotor phenotype between Chinese and Caucasian [2], which suggests   217
there could also be structural aspects of the iris which differ between populations that   218
affect PSO. However, Amatya, Gong, and Knox, 2011 suggest any differences between   219
populations may be the result of top-down executive functions [1]. A resolution of the   220
question of whether Chinese-Caucasian PSO differences are due to nature or nurture is   221
beyond the scope of the current paper. However, we hope that the data provided here   222
could provide new evidence about the origin of PSO.   223

    As pointed out by Nyström and Holmqvist, 2010 [25], PSOs are treated differently   224
across different oculomotor event detection algorithms and because fixations are defined   225
vaguely and implicitly in the literature [26], event detection algorithms may assign   226
PSOs to the saccades or merge them with the fixations. This means that depending on   227
the event detection algorithm used, differences in the PSOs between two groups may   228
yield different eye movement measures such as fixation and saccade duration between   229
the two groups. To see how much the saccade detection algorithm used by the EyeLink   230
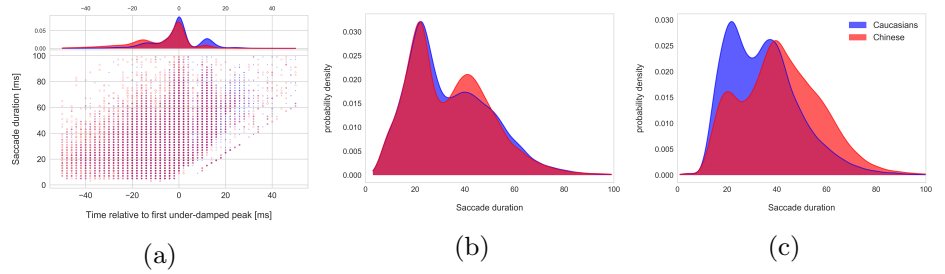
**Fig 5. Distribution of the saccade endings relative to the first under-damped peak(a), kernel density estimates of saccade duration based on saccade endings detected by the EyeLink software ($SE_{eyelink}$)(b), kernel density estimates of saccade duration based on saccade endings at the first under-damped peak ($SE_{t=0}$)(c). The Chinese and the Caucasians data are respectively represented by red and blue colors.**

software has been affected by the PSO differences of the two groups, we looked at the saccade offsets as detected by the EyeLink software ($SE_{eyelink}$) in relation to the first under-damped peak of the signals ($S(0)$). Figure 5a shows how saccade offsets are distributed around the time 0 where the first critical point of the saccade happens after the maximum velocity. While more than 60% of the saccade offsets detected by the EyeLink software were within the range of $[-10ms, 10ms]$ around the first under-damped peak, distribution of the saccade offsets around this time window differs in our two groups. This could be attributed to the difference in the PSO signals between the two groups. As we see in Figure 5a, there were many saccade offsets detected around 15 ms in the Caucasian group which is perhaps because of the changes in the saccade velocity around the second bump of the PSO. There were also more saccade offsets detected before time 0 in the Chinese group than in the Caucasian group. Figure 6 shows the PSO signals of two randomly chosen participants from each group as well as the saccade offsets indicated by vertical dashed lines.

The differences in the saccade detection between the two groups could result in the differences in the saccade duration. The higher number of saccade offsets detected before $t = 0$ in the Chinese group will reduce the average saccade duration for this group. Figure 5b shows the distribution of the saccade duration measured based on the saccade offsets detected by the EyeLink software $SE_{eyelink}$.

We saw no significant difference between the saccade durations of the two groups even though lower durations were expected for the Chinese group. In order to make the saccade offsets independent of the shape of the PSOs, we assumed that every saccade ends at $t = 0$ (referred to as $SE_{t=0}$), and we measured the saccade durations using the new endings (results shown in Figure 5c). By comparing the results with Figure 5b, it is clear that the EyeLink event detection algorithm has underestimated the saccade duration of the Chinese group.

Based on our findings, the size of the PSO signals are larger in the Chinese group for higher peak velocities. The oscillation of the pupil, relative to the eye at the end of each saccade presumably causes the visual input to oscillate slightly. It is unclear whether the visual input differs between the two groups as a result of differences in the post-saccadic oscillations. It may be that both groups have adapted different strategies for reducing perceptual wobble induced by large and fast saccades. Cultural elements have been studied to explain this difference. The experience with a given writing system is revealed to have a large impact on fixation durations and saccade lengths [13]. For example, Chinese words are constructed by sophisticated strokes with a mono-syllable
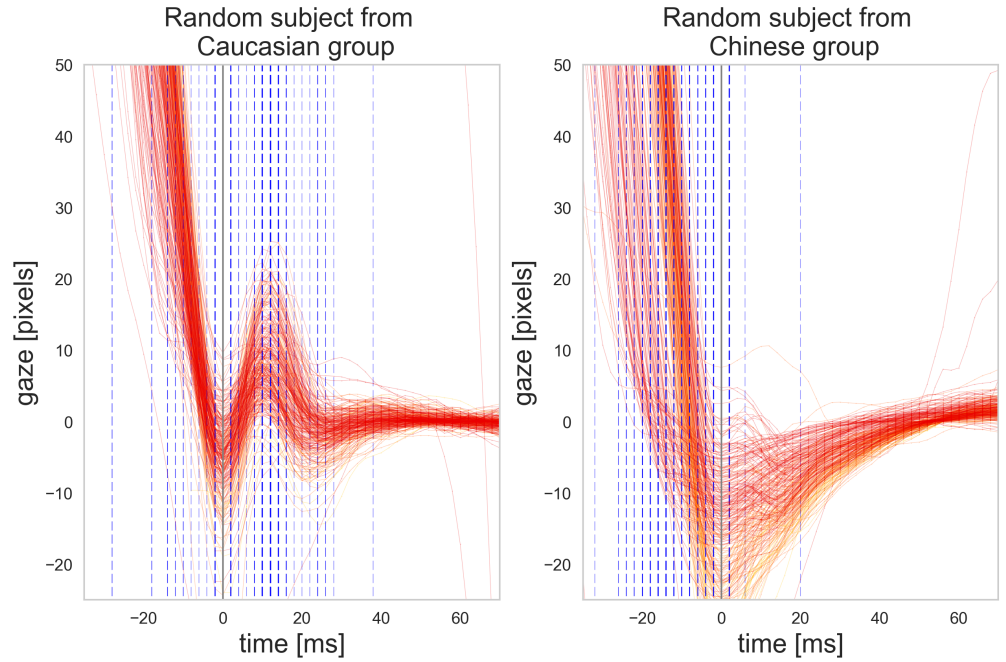
**Fig 6. All individual PSO signals for two randomly chosen participants from each group. The vertical dashed lines indicate the end of each saccade as detected by the EyeLink software.**

such that people need to pay more attention to details in order to recognize a word correctly, which might encourage Chinese to cultivate the habit of paying attention to details and contexts [27, 28]. This experience with different writing styles may affect PSO. However, how these between-group eye movement operate physically is unclear, our PSO signals were obtained from the gaze data and not the pupil center or iris center so it is difficult to ascertain the actual muscular source of the PSO.

## Conclusion

Post-saccadic oscillation eye movements (PSO) were compared between two different populations: university students born in China or in Europe. This study observed differences in PSO between Chinese and Caucasian participants. The differences in PSO signals were evident at different ranges of peak velocities where the size of the PSO signals were larger in the Chinese group compared to the Caucasian group. The results may indicate that Caucasians and Chinese have developed or are genetically predisposed to different strategies for reducing perceptual wobble after a saccade. It may be that these differences may be an extraneous variable which may need to be considered when measuring saccadic eye movements with video-based eye trackers. We Further showed that the differences in the PSO eye movements between two populations may affect the performance of the event detection algorithms which could result in the differences in the saccade duration between the two groups.

## Acknowledgments

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