Investigating phase noise in velocity-based optoretinography

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1. Introduction

In recent years the term optoretinography (ORG) has become synonymous for describing any imaging method that obtains stimulus-evoked functional responses from the retina non-invasively by using light [1]. Largely, the imaging systems utilize adaptive optics (AO), as it allows the visualization of individual photoreceptors and makes it possible to observe how they response to the stimuli. AO-based optical coherence tomography (OCT) has been especially suitable for this (both scanning and full-field implementations) as it gives access to the phase and offers information in 3D [2, 3]. By monitoring the optical path length difference (ΔOPL) between the inner segment / outer segment junction (IS/OS) and the cone outer segment tip (COST) over time, several research groups have shown how outer segment (OS) responds to stimulus by first contracting and then elongating [2, 3, 4, 5]. However, AO-based systems are complex and the amount of raw data they produce for ORG measurements does not enable real-time results, not to mention complexity of scanning-systems.

In velocity-based ORG the functional responses are obtained from tissue layers, eliminating AO altogether. Also rather than scanning 3D volumes over time, consecutive B-scans are taken from the same location, reducing the amount of data required. Temporal window (block size) is then selected and the instantaneous velocity for each spatial location is calculated by doing a linear fit within the temporal window. Rather than then measuring the OS length change (ΔOPL), OS velocity is monitored over time.

However, the velocity method suffers from phase-induced noise which is evident in the ORG signal before the stimulus is applied. A portion of the variation can be contributed to eye motion but not all. Here we investigated how the bulk motion correction and temporal time window selection (subsequently referred as block size) affects the noise in velocity-based ORG in order to bring the technology one step closer to the clinic.

2. Methods

The details of the velocity-based ORG-OCT system can be found elsewhere [6]. Briefly, it uses a 100 kHz swept-source at 1060 nm to image the retina at 400 Hz B-scan rate (Fig. 1(a)). After 40 ms, a stimulus flash is used (555 nm) to bleach 65% of M- and L-cones. Each healthy subject was dark adapted for five minutes before imaging and imaging locations ranged from 2 to 10 degrees temporal. This study adhered to the Declaration of Helsinki and was approved by the UC Davis IRB.

A resulting velocity ORG curve can be seen in Fig. 1(b). Each acquired dataset is processed multiple times with varying parameters. First bulk motion correction is used and the block size (temporal window) is varied from 2 to 6 B-scans (5 ms to 15 ms). Then bulk motion correction is turned off and the process of varying the block size is repeated. The resulting ORG curve was then split into three distinct phases for the analysis: prestimulus (< 0 ms), early response (0-20 ms) and late response (20-40 ms). Standard deviation of the pre-stimulus signal determined our noise floor. For the signal-to-noise ratios (SNRs), local minima between 0-20 ms was extracted (v_{min}) and divided with the noise floor, resulting in early response SNR. For the late response SNR, the velocity ORG signal was averaged between 20-40 ms (v_{20-40}) and again divided by noise floor.

3. Results and discussion

Figure 2 show our first results from three healthy subjects. In Fig. 2(a), early (v_{min}) and late (v_{20-40}) response SNRs are compared when using different block sizes (temporal windows) from 2 degree temporal and bulk motion correction kept active. Between block sizes 2 to 5 there is approx. 10 % variation with block size 6 showing more significant decrease, likely due to the fact that the contractile phase of the cone happens during the first 10 ms and longer temporal window averages more of the elongation. The late response SNR shows steady increase with increasing block size and SNR is doubled from size 2. In Fig. 2(b) initial

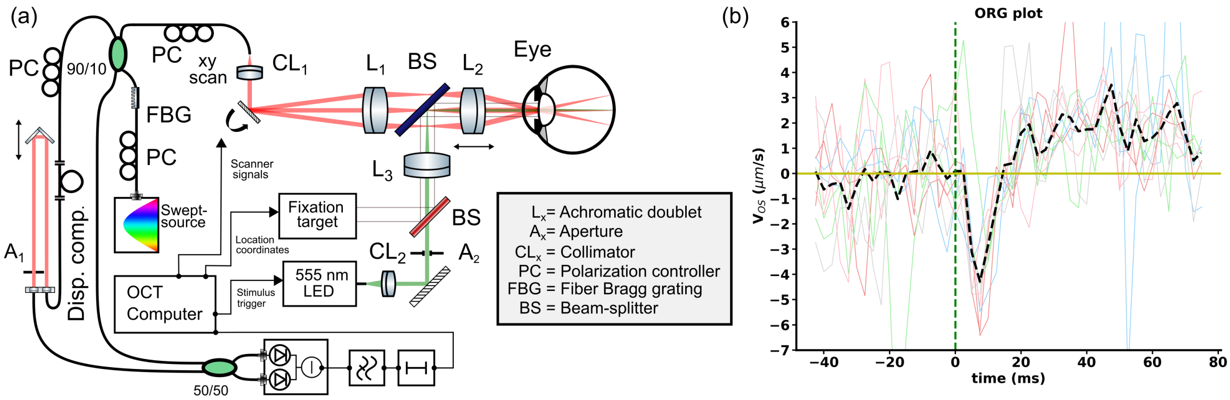

Fig. 1. ORG-OCT system and ORG velocity curve. (a) Optical schematic of the OCT system showing the key components as well as the implementation of the stimulus channel and fixation modules. (b) An example of the averaged velocity curve from several different trials taken from 2 deg. temporal with 65 % stimulus bleaching. Despite averaging, there is still variation in the signal prior to stimulus flash, which indicates presence of noise.

comparison using block size 2 was done with bulk motion on and off. Opposite to our speculations, the SNR dropped more than a half when bulk motion correction wasn't used, indicating that it still plays a role in the phase stability even when we are monitoring tissue layers within the B-scan itself. These results can be considered preliminary as the data processing of all the different datasets is still on-going, including different temporal locations and additional subjects.

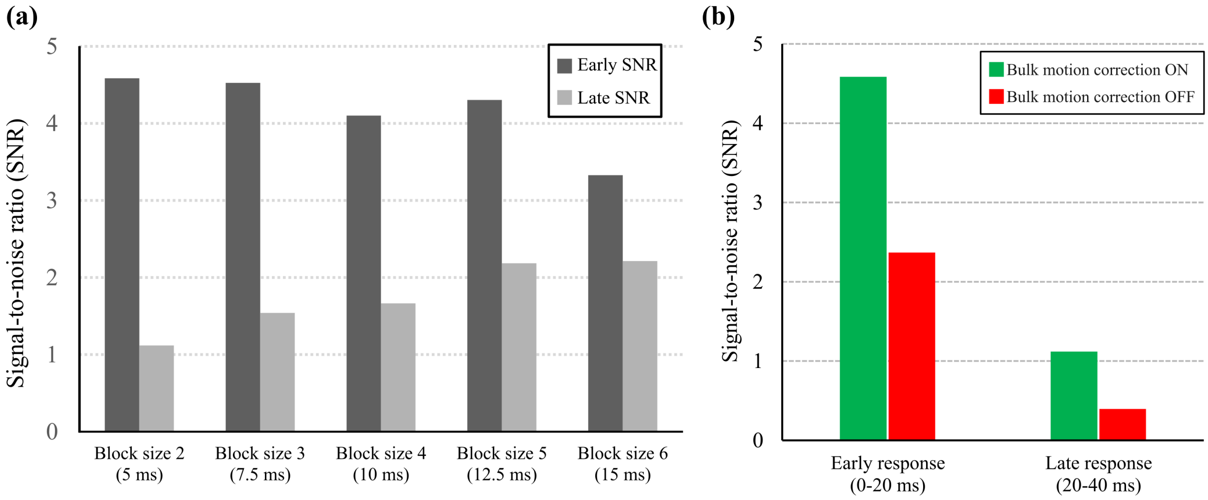

Fig. 2. Impact of block size and bulk motion correction in SNR when using 65 % bleaching and imaging 2 degree temporal. (a) As the temporal window is increased and bulk motion correction enabled, the late response SNR increases slowly and doubles when temporal window is three times as large. Early response has consistent SNR (approx. 10% variation) and only significantly decreases when block size is 6. (b) The use of bulk motion correction has a clear impact on the SNR and without it, both early and late response SNRs are reduced by a factor of 2.

4. References

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