Hiding graphic updates during long saccadic suppression periods

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Abstract. During visual exploration of a scene human beings can be insensitive to even large changes in the scene when the eye is executing rapid or saccadic eye movements. In this contribution, this period of saccadic suppression was exploited to hide graphics updates in immersive environments. Two experiments were conducted. In the first experiment the general sensitivity of observers to trans-saccadic translations of large images of complex natural scenes was studied. It was found that trans-saccadic changes of up to 1.2 degrees of visual angle were seldom noticed during saccades with duration of at least 66 ms. In the second experiment, the perceived magnitude of trans-saccadic translation was compared to the perceived magnitude of image translation when no saccade was performed to determine the point of subjective equality. It was found that trans-saccadic displacements were perceived as approximately half as big as equivalent sized inter-saccadic displacements.

1. Introduction

In virtual environments, changes of the visualization are often necessary to correct the simulation state in response to sensor updates [1] or changes in the state of remote entities. Introducing these changes suddenly can be perceptually disruptive. This paper describes a method that allows graphic updates while the observer's sensitivity to the changes is reduced. Specifically, graphics updates were hid during the period of visual suppression that accompanies a rapid, or saccadic, eye movement. If a graphics update is pending and a saccadic eye movement is detected then the update is performed during the saccade [2]. Saccadic suppression prevents these saccade-contingent updates from being apparent.

To appreciate a natural or computer-generated scene, fast eye movements called saccades must be used to direct the eye to areas of interest in the scene. During these saccades, images of objects will stream across the retina at hundreds of degrees per second. Despite this disjoint motion of the retina, the world does not appear disjoint or unstable and motion blur during saccades is not apparent. Part of the reason is that, during saccades, sensitivity to visual stimuli is reduced [3,4].

In a first experiment, the general sensitivity of observers to large trans-saccadic image translations was studied. The detectability of trans-saccadic scene changes was evaluated using images of high resolution real world scenes. A second experiment was designed to compare the perceptual effects of trans-saccadic image displacements with displacements that occurred between saccades.

Figure: 1 Eye-tracking system used in the immersive environment at York University [5].

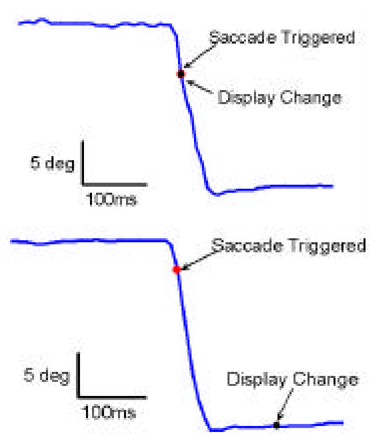

Figure 2: Graph of a saccade showing when the scene change during a saccade (trans-saccadic change) (top) and the control condition shortly after a saccade (inter-saccade change) (bottom) was triggered.

2. Experiments

2.1 Apparatus, Material and Subjects

The eye tracking system was based on the Vision 2000 video eye-tracking system by EL-MAR Inc. (Toronto, Canada) (see fig. 1), which uses an adaptive real-time image processing technique to obtain accurate measurements of the eye movement. The eye position is measured at a frequency of 120Hz and sent to a Linux workstation over a RS232 serial port at a baud-rate of 38400. A standard Linux workstation (dual AMD Athlon MP 1900+ processors, 1024 MB System RAM, GeForce4 TI4600, RedHat Linux with kernel version 2.4.18) is used to render the stimuli, process eye movement data and control the sequencing of the experimental stimuli. Images were presented on a Barco 808 CRT projector with a resolution of 1024x768 and a refresh rate of 120 Hz. Viewing was binocular at a distance of 80 cm.

Images of complex natural scenes (see fig. 3) were recorded with a Nikon Coolpix5400 digital camera at a resolution of 5.1 megapixels and down-sampled to the screen resolution of 1056x792. During the trials, images were translated horizontally in different discrete steps. The image needed to be bigger than the actual screen-size of 1024x768 so that image translations could be performed without shifting the border of the screen. Translation direction (right or left) was chosen randomly for each trial. During each trail, one of three different types of saccade-contingent displacements of a scene was imposed (see fig. 2):

1. Trans-Saccadic displacements
2. Inter-Saccadic displacements
3. no image displacement

Overall system latency of the detection and the update processes was such that saccade-contingent changes could be introduced for saccades longer than 66 ms in duration if the saccade was detected within 16-24 msec. of its initiation. To meet these demands, real time algorithms for saccade detection and duration estimation were developed and their performance evaluated [2].

Figure 3: Sample images shown to the participants in both experiments

Subjects with normal ocular motility and vision were recruited to participate in these studies. Six subjects served in experiment 1 (one female and five male) ranging in age from 22 to 38 years. Five subjects served in experiment 2 (one female and four male) ranging in age from 22 to 39 years.

For experiment 1, a single center point calibration has been applied. During calibration it was confirmed that the accuracy of this procedure was sufficient given that no high accuracy point of regard measurements had to be performed. For experiment 2 however, a ten point calibration routine (five horizontal and five vertical) was applied. The horizontal points were evenly distributed between -15 and +15 degrees and the vertical points between -11 and +11 degrees of viewing angle.

2.2 Methods of Experiment 1

Participants viewed a set of 45 images in a random order. Each image was shown for 10 seconds. The trials were divided into five categories. Four of them were saccade-contingent horizontal image displacements of various sizes - 0.0, 0.4, 0.8 or 1.2 degree in terms of visual angle from the eye position of the subject. One was a control condition that had changes that were not synchronized with an eye movement. Ten images were randomly assigned to each category of saccade-contingent displays and five images to the control condition. The image changes in the control condition were expected to be easily detected if the subjects did not coincidentally perform a blink or a saccade. Subjects were asked to study the scenes and memorize them in order to perform a memory test afterwards. The purpose of this task was to ensure that subjects actively viewed the scenes and thus execute a sufficient number of saccades.

After the image was shown for 10 seconds a black screen cued the subject to indicate whether there was a change in the last scene or not. After entering the decision the next image was shown. The frequency of the changes was not communicated to the subjects. Each scene was changed once per saccade-contingent trial. The changes were triggered at the third saccade detected in the viewing period for each trial. Since the scenes were shown in random order neither the direction nor the category was predictable.

2.3 Methods of Experiment 2

In each session, participants viewed 80 pairs of images in a randomly ordered 2IFC experiment (see fig. 4). For each trial, in one interval there was a test stimulus and in the other a reference stimulus. The test could either be trans-saccadic or inter-saccadic. This experimental design allowed for comparison of the perception of trans-saccadic changes with inter-saccadic changes of various magnitudes. Stimulus presentation time was reduced to 2 seconds, compared to 10 seconds in experiment 1, due to the large number of trials required. Since presentation time was shortened, changes were triggered after the second saccade in the stimulus interval (rather than the third as in experiment 1). One further change in the procedure was that the inter-saccadic changes were timed to occur 150 ms after the saccade occurred since it can be assumed that no further saccades can be performed in refractory period following the saccade. This procedure reduced the chance of a coincidental saccade occurring during or near the image translation.

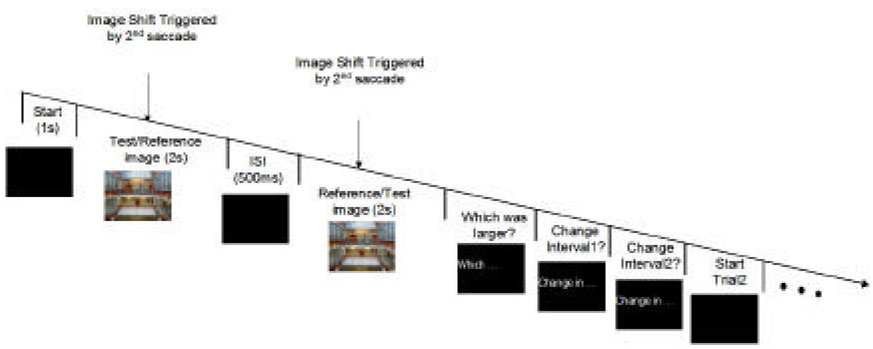

Figure 4.: Procedure of experiment 2. Either reference or test image is shown for two seconds. The other stimulus is then displayed following a 500 ms interval when a black image was shown. After both intervals the subjects responses were recorded.

For the test stimulus the change could be either trans-saccadic or inter-saccadic. For both cases displacements of 0.6 and 1.2 degrees were randomly chosen. The reference stimulus was randomly varied for the 0.6 displacement case of the test stimulus between 0.075 and 0.75 degree and for the 1.2 displacement case between 0.6 and 1.8 degrees in discrete steps. Half of the trails have been assigned to the control condition in which test and reference stimulus were both inter-saccadic.

After displaying the test and the reference stimulus the subjects were asked three questions (see fig. 4): 1. Which displacement was larger? 2.Was there a change in interval 1? 3.Was there a change in interval 2? The first question relates to the goal of this experiment to determine the relative apparent magnitude of saccade-contingent and inter-saccadic movements. The second and third question were needed to ensure that subjects detected both changes before making these comparisons. If subjects did not perceived changes in the reference image the trail was excluded from further evaluation. Eye blink contaminated data and failures, which could occur if insufficient saccades were detected during either of the presentation intervals of a trial, were excluded from the evaluation. While the ratio of failures vary from more than 60% to less than 5% per subjects, eye blinks did not cause a major influence to the evaluation of the data.

3. Results

3.1 Experiment 1

Saccades that met the threshold criterion occurred an average of 5.9 times per picture. Subjects acted conservatively – as no false alarms were seen during the no-change condition. Misses for inter-saccadic changes were rare and always associated with a coincidental saccade or blink. Most trans-saccadic detections (hits) were associated with short saccade durations in the order of the system delay. Detection rate decreased if the saccade length increased. For saccades with duration of at least 66 ms, trans-saccadic changes were seldom noticed. Dependent on the size of the translations 93 to 82 percent of the changes stayed undetected (see fig. 5). During the control conditions some changes were unexpectedly missed. On further analysis it was found that these misses were associated with coincidental saccades. As a result, in the second experiment the control was triggered during the refraction time after a saccade.

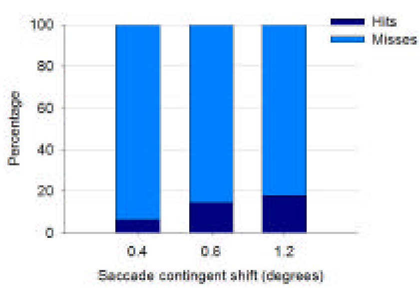

Figure 5: Hits and miss rate for saccade contingent shifts during large saccades (> 66 ms).

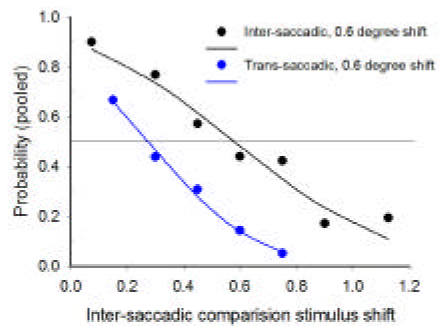

Figure 6: Probability of seeing the test stimulus as larger than the inter-saccadic comparison for 0.6 degree displacement test stimuli.

3.2 Experiment 2

In trails in which both the test stimulus and the reference stimulus were successfully detected (second last row of table 1) we analysed the perceived magnitude of the test stimuli. Since quite a high percentage of changes were missed due to trans-saccadic suppression (and some misses of inter-saccadic stimuli), multiple sessions per subject were required to obtain meaningful data. Two subjects performed eight sessions, two subjects four sessions and one subject two sessions. Trans-saccadic changes appeared approximately 50% smaller than equivalent inter-saccadic changes (see fig. 6). Hit and miss rate followed the pattern of the first experiment.

Test detec. (trans-sacc)	Referenc. detected	0.6 deg. subj. 1	1.2 deg subj. 1	total subj. 1	0.6 deg subj. 2	1.2 deg subj. 2	total subj. 2
no	no	18	15	33	20	9	29
yes	no	8	15	23	10	17	27
no	yes	78	64	142	77	63	140
yes	yes	40	53	93	41	49	90
total		144	147	291	148	138	286

Table 1: Detection results for two subjects showing the relationship between detected test stimulus in the trans-saccadic case (test) relative to an inter-saccadic stimulus (reference).

4. Conclusions

Trans-saccadic changes are suppressed for stimuli filling a large part of the visual field, particularly for long duration saccades. When a trans-saccadic change (motion) is detected it appears slower than an equivalent inter-saccadic change (see fig. 7). Trans-saccadic displacements were perceived as approximately half as big as equivalent sized inter-saccadic displacements (see fig. 6). When overcoming the overall system latency comparable results should be obtainable for shorter saccades. Saccadic suppression could possibly be used to hide instantaneous scene or database updates in distributed virtual environments ([5] see fig .1).

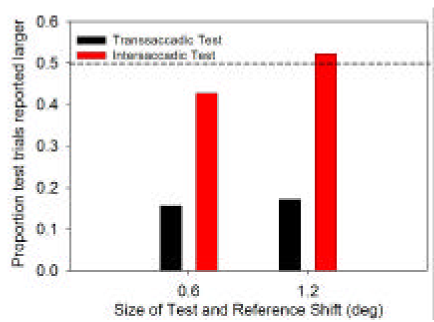

Figure 7: Proportion of test trails reported larger than an equivalent sized comparison trial (when the change was detected in both intervals) for the displacements of 0.6 and 1.2 degrees.

Acknowledgements R. Herpers gratefully acknowledges the support of the Deutsche Forschungsgemeinschaft (DFG) grant HE 2967/2-1, which partially funded the presented work. R. S. Allison gratefully acknowledges the support of CRESTech and NSERC (Canada).

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