

# Journal of Visualized Experiments

## Investigating the Deployment of Visual Attention before Accurate and Averaging Saccades Via Eye Tracking and Assessment of Visual Sensitivity --Manuscript Draft--

Article Type:	Invited Methods Article - JoVE Produced Video
Manuscript Number:	JoVE59162R2
Full Title:	Investigating the Deployment of Visual Attention before Accurate and Averaging Saccades Via Eye Tracking and Assessment of Visual Sensitivity
Keywords:	eye tracking; Psychophysics; saccade; averaging saccade; global effect; Attention; Visual attention; spatial attention; presaccadic attention; premotor theory of attention
Corresponding Author:	Luca Wollenberg GERMANY
Corresponding Author's Institution:	
Corresponding Author E-Mail:	wollenberg.luca@gmail.com
Order of Authors:	Luca Wollenberg Heiner Deubel Martin Szinte
Additional Information:	
Question	Response
Please indicate whether this article will be Standard Access or Open Access.	Open Access (US\$4,200)
Please indicate the <b>city, state/province, and country</b> where this article will be <b>filmed</b> . Please do not use abbreviations.	Munich, Bavaria, Germany



**Luca Wollenberg**

Ludwig-Maximilians-Universität München

Leopoldstr. 13, 80802, Munich, Germany

luca.wollenberg@gmx.de

Dear Editors,

Upon invitation by editorial manager Aaron Berard we wish to submit our manuscript entitled << Eye Tracking and Presaccadic Assessment of Visual Sensitivity: Revealing the Deployment of Visual Attention Before Accurate and Averaging Saccades >> for an open access publication in JoVE.

Note that the submitted manuscript is based on a recent publication in PLOS Biology:

Wollenberg, L., Deubel, H., & Szinte, M. (2018). Visual attention is not deployed at the endpoint of averaging saccades. *PLoS biology*, 16(6), e2006548.

Luca Wollenberg

on behalf of Heiner Deubel and Martin Szinte

**TITLE:**

Investigating the Deployment of Visual Attention before Accurate and Averaging Saccades Via Eye Tracking and Assessment of Visual Sensitivity

**AUTHORS AND AFFILIATIONS:**

Luca Wollenberg<sup>1,2 \*</sup>, Heiner Deubel<sup>1</sup>, & Martin Szinte<sup>1,3</sup>

<sup>1</sup>Allgemeine und Experimentelle Psychologie, Ludwig-Maximilians-Universität München, Munich, 80802, Germany

<sup>2</sup>Graduate School of Systemic Neurosciences, Ludwig-Maximilians-Universität München, Planegg-Martinsried, 82152, Germany

<sup>3</sup>Department of Cognitive Psychology, Vrije Universiteit Amsterdam, Amsterdam, 1081BT, Netherlands

**Corresponding Author:**

Luca Wollenberg (wollenberg.luca@gmail.com)

Tel: +49 (0) 89 / 2180 6229

**Email Addresses of Co-authors:**

Heiner Deubel (heiner.deubel@psy.lmu.de)

Martin Szinte (martin.szinte@gmail.com)

**KEYWORDS:**

eye tracking, psychophysics, saccade, averaging saccade, global effect, attention, visual attention, spatial attention, presaccadic attention, premotor theory of attention

**SUMMARY:**

This experimental protocol combined eye tracking and the assessment of presaccadic visual sensitivity in a dual task paradigm, consisting of a free choice saccade task and a visual discrimination task, to investigate the deployment of visual spatial attention before both, accurate and averaging saccades.

**ABSTRACT:**

This experimental protocol was designed to investigate whether visual attention is obligatorily deployed at the endpoint of saccades. To this end, we recorded the eye position of human participants engaged in a saccade task via eye tracking and assessed visual orientation discrimination performance at various locations during saccade preparation. Importantly, instead of using a single saccade target paradigm for which the saccade endpoint typically coincides roughly with the target, this protocol comprised the presentation of two nearby saccade targets, leading to a distinct spatial dissociation between target locations and saccade endpoint on a substantial number of trials. The paradigm allowed us to compare presaccadic visual discrimination performance at the endpoint of accurate saccades (directed towards one of the saccade targets) and of averaging saccades (directed to an intermediate location in between the two targets). We observed a selective enhancement of visual sensitivity at the endpoint of

accurate saccades but not at the endpoint of averaging saccades. Rather, before the execution of averaging saccades, visual sensitivity was equally enhanced at both targets, suggesting that saccade averaging follows from unresolved attentional selection among the saccade targets. These results argue against a mandatory coupling between visual attention and saccade programming based on a direct measure of presaccadic visual sensitivity rather than saccadic reaction times, which have been used in other protocols to draw similar conclusions. While our protocol provides a useful framework to investigate the relationship between visual attention and saccadic eye movements at the behavioral level, it can also be combined with electrophysiological measures to extend insights at the neuronal level.

## **INTRODUCTION:**

Accumulated evidence argues for strong coupling between oculomotor and attentional control. The influential premotor theory of attention<sup>1,2</sup> provides a particularly strict account regarding this coupling, suggesting that covert shifts of visual attention correspond to saccade programming without subsequent execution. Indeed, shared neuronal correlates of attentional and oculomotor control have been identified via functional magnetic resonance imaging (fMRI)<sup>3</sup> and sub-threshold micro-stimulation of the Frontal Eye Fields (FEF) and the Superior Colliculi (SC) produces attentional benefits measured both behaviorally and electrophysiologically at the stimulated movement field position, even if no eye movements are induced<sup>4,5,6,7</sup>. Psychophysical experiments furthermore revealed that visual attention is consistently shifted towards the target of a saccade during oculomotor preparation<sup>8,9</sup>. However, dissociations at the neuronal level<sup>10,11,12</sup> and observations that saccade preparation does not necessarily entail a corresponding shift of attention<sup>13,14,15,16</sup> cast some doubt on an obligatory coupling between saccade programming and visual spatial attention.

Here, we revisited the nature of the coupling between attention and oculomotor programming at the behavioral level using a dual task which entailed a free choice saccade task and a visual discrimination task. Crucially, two saccade targets were presented at an angular distance of 30° on half of the trials, producing a distinct global effect<sup>17,18,19,20</sup> associated with a substantial number of saccades landing in between the two targets (averaging saccades). Since we randomly presented a discrimination target shortly before saccade onset at one out of 24 equidistant locations (including the two saccade target locations, the location in between them and 21 control locations), we were able to assess and compare the presaccadic deployment of visual attention when saccade goal and saccade endpoint were either spatially associated (accurate saccades) or dissociated (averaging saccades).

To test whether visual attention is an obligatory consequence of oculomotor programming, and, therefore, always shifted towards the saccade endpoint, we analyzed visual sensitivity for all 24 locations as a function of the saccade landing direction. While accurate saccades were associated with a consistent presaccadic enhancement of visual sensitivity at their endpoint, we found no such enhancement at the endpoint of averaging saccades. This dissociation rules out an obligatory coupling of visual attention to the executed oculomotor program at the behavioral level and suggests that attentional and oculomotor control are dissociable at some cortical or subcortical processing stage. Importantly, we observed an equal enhancement of visual

sensitivity at the two saccade targets before averaging saccades, suggesting that the global effect arises from unresolved saccade target selection before saccade onset.

## **PROTOCOL:**

This protocol was designed according to the ethical requirement specified by the Ludwig-Maximilians-Universität München and with the approval of the ethics board of the department.

### **1. Participants**

1.1 Recruit a sufficient number of naive participants with normal or corrected-to-normal vision and without neurological or psychiatric disorders. 10 participants are recommended based on similar, recent protocols<sup>21,22</sup>.

NOTE: Overall, we recruited 13 participants (aged 20-28, 7 females, 12 right-eye dominant, 1 author) from which 3 were excluded from final analysis since their orientation discrimination performance remained at chance level for all tested locations.

### **2. Experimental Setup**

2.1 Conduct the experiment in a quiet and dimly illuminated room under the supervision of an experienced experimenter familiar with eye tracking and all other experimental components.

2.2 Prepare an experimental setup consisting of a computer, a cathode-ray tube (CRT) monitor, a standard keyboard, two loudspeakers, and an eye tracker (see **Table of Materials**).

2.2.1 Sequence and control the experiment using an appropriate software (see **Table of Materials**). Write a script which can be run on the software to load and launch the experiment automatically for each participant (<https://github.com/mszinte/CompAttExo>). Ensure that the script encodes all necessary experimental parameters and implements stimulus presentation as well as behavioral and eye data collection.

2.2.2 Display all visual stimuli on a CRT screen with a minimum vertical refresh rate of 120 Hz. Ensure the proper display of visual Gabors via gamma linearization of the experimental screen.

2.2.3 Assess participants' evaluation of the discrimination target orientation (counterclockwise vs. clockwise) via the left and right arrow keys on a standard keyboard.

2.2.4 Provide auditory feedback via loudspeakers upon incorrect manual responses.

### **3. Eye Tracking**

3.1 Record the gaze of participants' dominant eye at a sampling rate of at least 1 kHz throughout the entire experiment via an eye tracker.

3.2 Ask the participant to sit down comfortably on a chair, place their chin on a chinrest, and lean their forehead against a bar to restrain head movements during the experiment. Individually adjust the height of the chair, the chinrest and the forehead bar such that participants' eyes align with the center of the experimental monitor.

### 3.3 Individual Eye Tracker Calibration

3.3.1 Before each experimental block (duration: approximately 10 min) and whenever necessary (e.g. after noticeable head movements and resulting shifts of the estimated fixation), run a calibration procedure to guarantee that participants' gaze can be accurately tracked within a radius of  $1^\circ$ .

NOTE: Here, we used a 13-point calibration procedure to get an accurate estimate of the characteristic light reflections (pupil and corneal reflection) of the tracked eye as a function of the gaze.

3.3.1.1 Ask the participant to follow a dot moving across different locations on the screen with their eyes to estimate their gaze position.

3.3.1.2 Repeat the procedure with a dot rotation of  $30^\circ$  and compare the measured gaze position to the estimated gaze position to validate the initial calibration. The calibration can be considered accurate when the averaged difference between the estimated gaze position following the calibration stage and the measured gaze position in the validation stage is below  $1^\circ$ .

3.3.1.3 Repeat the calibration procedure whenever the participant breaks fixation repetitively to guarantee high tracking accuracy throughout the experiment.

3.4 During the experiment, monitor correct fixation at the screen center at the beginning of each trial. Only start a trial if the gaze stays within a radius of  $2^\circ$  around the central fixation target for at least 200 ms.

## 4. Instructions

4.1 Provide participants with clear task instructions. Present the task instructions at least once at the beginning of each experimental session in the form of a written text, together with a visualization of the trial chronology. Encourage participants to carefully read through the instructions and to ask remaining questions to the experimenter.

NOTE: The instructions, as presented to the participants before each block, are shown in **Figure 1**.

4.1.1 Instruct the participant to fixate at the center of the screen at the beginning of each trial.

4.1.2 Inform the participant that 24 flickering distractor streams will appear on the screen and

that two of them will be cued by white frames, which will either be flashed shortly or remain on the screen until the trial end.

4.1.3 Ask the participant to execute a saccade towards the center of one of the two cued distractor streams at free choice. Emphasize that participants should move their eyes as fast and as accurately as possible upon the onset of the cues.

4.1.4 Inform the participant that, for a short duration during the trial, a tilted Gabor will be presented randomly at one of the 24 distractor streams.

4.1.5 Ask the participant to manually report whether the tilted Gabor was rotated clockwise or counterclockwise relative to the vertical by pressing the right or left arrow on the keyboard, respectively. Explain that a sound will be played if the orientation of the tilted Gabor is being reported incorrectly.

## 5. Experimental Design, Stimuli and Trial Chronology

5.1 Ensure to partition the experiment into at least two experimental sessions on different days to guarantee participants' concentration across the entire duration of the experiment. Within an experimental session, prompt participants to take short breaks in between consecutive blocks.

NOTE: This experiment consisted of 24 blocks, each including 290 online correct trials (all trials without fixation breaks and with a saccade onset between 50 and 350 ms after the saccade targets onset; incorrect trials were repeated at the end of a block), amounting to a total duration of about 5 h.

5.2 Deliberately predefine stimulus features (color, luminance, and size), stimulus timing, and a viewing distance which ensures the desired angular stimulus size. While most features of the visual stimuli (e.g., size, luminance, and contrast) can be adjusted to account for specific experimental purposes based on piloting, precise stimulus timing is crucial to assess visual attention during the presaccadic interval.

### 5.3 Stimuli and Trial Chronology

5.3.1 Present all stimuli on a gray ( $\sim 19.5 \text{ cd/m}^2$ ) background in order to minimize visual and screen aftereffects.

NOTE: A visualization of the experimental procedure can be found in **Figure 2**.

5.3.2 Present a fixation target (FT) in the form of a black ( $\sim 0 \text{ cd/m}^2$ ) and white ( $\sim 57 \text{ cd/m}^2$ ) "bull's eye" ( $0.4^\circ$  radius) at the screen center at trial start. Remove the fixation target from the screen together with the onset of the saccade targets.

5.3.3 Display 24 evenly spaced distractor streams (DS) at a radius of  $10^\circ$  from the fixation target at the trial start. Use dynamic stimuli, alternating every 25 ms (40 Hz) between a vertical Gabor patch (frequency: 2.5 cpd; 100 % contrast; random phase selected each stream refresh; SD of the Gaussian window:  $1.1^\circ$ ; mean luminance:  $\sim 28.5 \text{ cd/m}^2$ ) and a Gaussian pixel noise mask (made of approximately  $0.22^\circ$  width pixels with the same Gaussian envelope as the Gabors).

NOTE: The use of flickering noise helps to minimize attentional capture due to sudden onsets that are normally associated with static stimuli and thus reduces discrimination target detectability without the concurrent selective deployment of attention<sup>21</sup>.

5.3.4 Between 300 and 600 ms (in steps of the screen refresh rate of  $\sim 8$  ms) after the onset of the fixation target, present two saccade targets ( $ST_1$  and  $ST_2$ ) in the form of gray circles ( $\sim 39 \text{ cd/m}^2$ ;  $1.1^\circ$  radius;  $0.2^\circ$  width) surrounding two randomly chosen distractor streams. Ensure to vary the time of saccade target onset from trial to trial to avoid that participants adopt a predictive saccade execution pattern.

5.3.4.1 Randomly present the two saccade targets at an angular distance of either  $30^\circ$  or  $90^\circ$  across trials.

5.3.4.2 Randomly display the saccade targets for either 50 ms (transient cueing condition:  $tST_{1+2}$ ) or until the end of the trial (continuous cueing condition:  $cST_{1+2}$ ) across trials.

5.3.5 Randomly present a discrimination target (DT) at one of the 24 distractor streams and between 75 and 175 ms after the onset of the saccade targets. Display the discrimination target, a tilted Gabor patch, rotated clockwise or counterclockwise by  $12^\circ$  relative to the vertical, for 25 ms to replace the vertical Gabor patch within the randomly selected distractor stream. Select the time window for discrimination target presentation to maximize the number of trials in which the discrimination target offset occurred before saccade onset.

NOTE: The applied tilt level of the discrimination target was derived from pretests with the objective of producing visual discrimination performance above the chance level at attended locations. The tilt level can be generally changed but experimenters should first test whether participants can properly discriminate the target angle at least at the cued locations.

5.3.6 Erase all stimuli from the screen 500 ms after the onset of the saccade targets such that only the gray background remains.

5.3.7 Wait for the participant to indicate the orientation of the discrimination target via the keyboard (by pressing the left arrow for counterclockwise orientations and the right arrow for clockwise orientations) and play a feedback sound whenever participants report the discrimination target orientation incorrectly. Start the next trial once a manual response was given.

## 6. Data Preprocessing and Analysis



6.1 Process the recorded eye data before proceeding to final data analysis. Only include trials in which the participant maintained the fixation within a  $2^\circ$  radius around the fixation target without blinking and initiated a saccade landing between  $7^\circ$  and  $13^\circ$  from the fixation target (*i.e.* within  $\pm 30\%$  of the instructed saccade size). Ensure that any measure of visual sensitivity was collected during the presaccadic interval by including only those trials in which the discrimination target offset occurred before the saccade onset.

NOTE: In total, 75.7% of all trials were included in the final analyses after eye data preprocessing.

6.2 In order to analyze data as a function of the location of the discrimination target relative to the location of the saccade targets, rotate the stimulus configuration of each trial as to align the saccade target locations symmetrically around the geometrical angle 0 of the stimulus stream orbit.

6.3 Split trials as a function of the saccade landing direction. To do so, divide the entire stimulus stream orbit into 24 even angular sectors of  $15^\circ$  ( $\pm 7.5^\circ$ ) centered on each distractor stream and combine trials entailing saccades directed towards the same respective sector.

6.4 Define visual sensitivity as:  $d' = z(\text{hit rate}) - z(\text{false alarm rate})$ . Count clockwise responses to clockwise discrimination targets as hits and clockwise responses to counterclockwise discrimination targets as false alarms (and vice versa). Substitute discrimination performance values of 100% and 0% by values of 99% and 1%, respectively, before transforming them into  $d'$ . Transform discrimination performance values below the chance level (50% or  $d' = 0$ ) into negative  $d'$  values.

## REPRESENTATIVE RESULTS:

Here, we only present some central, representative results. The entirety of results can be found in our recent publication<sup>23</sup>. Note that data were mainly analyzed irrespective of the duration of the saccade targets (*i.e.* transient and continuous cueing conditions were combined for the final analyses). For statistical comparisons, we drew 10000 bootstrap samples (with replacement) from the distribution of single subject means and derived two-tailed  $p$  values from the distribution of differences between the bootstrapped samples.

The detection of saccade onsets and offsets was based on the velocity distribution of the gaze<sup>24</sup>. We used a moving average over 20 subsequent eye-position samples to determine saccade onsets/offsets whenever the velocity of the eye exceeded/fell below the median of the moving average by 3 SDs for at least 20 ms. Corrective saccades were defined as eye movements executed after the offline selected main saccade sequence and were only included in the respective corrective saccade analysis if they landed between  $7^\circ$  and  $13^\circ$  from the fixation target and were initiated within the first 500 ms following the main saccade sequence as well as before the participant's manual response.

Before proceeding to final data analysis, data were rotated (see 6.2). Consequently, after data

rotation, the most counterclockwise saccade target  $ST_1$  was always represented at  $+45^\circ/+15^\circ$  (in the  $90^\circ$  and  $30^\circ$  conditions, respectively), the location BTW in between the saccade targets at  $0^\circ$  (in both the  $90^\circ$  and  $30^\circ$  conditions), and the most clockwise saccade target  $ST_2$  at  $-45^\circ/-15^\circ$  (in the  $90^\circ$  and  $30^\circ$  conditions, respectively) relative to the angle 0. Locations other than  $ST_1$ ,  $ST_2$ , and BTW were considered as control locations (CTRL) in both, the  $90^\circ$  and  $30^\circ$  conditions.

Our protocol allowed us to evaluate saccades in response to oculomotor competition among two saccade targets presented at different angular distances based on the recorded eye data. As expected, the saccade endpoint distributions associated with the  $90^\circ$  (**Figure 3A and 3C**) and  $30^\circ$  (**Figure 3B and 3D**) conditions differed substantially. We observed mostly accurate saccades towards one of the saccade targets in the  $90^\circ$  condition, where  $41.0\% \pm 1.0\%$  of saccades ended within the sector including the most counterclockwise saccade target  $ST_1$  and  $41.8\% \pm 1.9\%$  within the sector including the most clockwise saccade target  $ST_2$  (**Figure 3C**). In the  $30^\circ$  condition, in contrast, participants executed a substantial number of averaging saccades. Here,  $33.6\% \pm 2.4\%$  of the saccades ended within the sector in between the 2 saccade targets BTW,  $29.95\% \pm 1.6\%$  ended within the sector including  $ST_1$ , and  $32.0\% \pm 1.8\%$  within the sector including  $ST_2$  (**Figure 3D**).

Furthermore, the assessment of visual sensitivity at all 24 locations distributed across the visual field allowed us to analyze the spatial deployment of attention during oculomotor programming in detail. Overall, taking into account saccades of all directions, we observed a selective facilitation of visual sensitivity at the two saccade targets relative to the control locations CTRL (corresponding to the average across all positions except for  $ST_1$ ,  $ST_2$ , and BTW) in both the  $90^\circ$  ( $ST_1$ :  $d' = 2.2 \pm 0.3$  versus CTRL:  $d' = 0.3 \pm 0.1$ ,  $p < 0.0001$ ;  $ST_2$ :  $d' = 2.2 \pm 0.4$  versus CTRL,  $p < 0.0001$ ;  $ST_1$  versus  $ST_2$ ,  $p = 0.8964$ ; **Figure 4A**) and  $30^\circ$  ( $ST_1$ :  $d' = 2.2 \pm 0.3$  versus CTRL:  $d' = 0.3 \pm 0.1$ ,  $p < 0.0001$ ;  $ST_2$ :  $d' = 2.1 \pm 0.3$  versus CTRL,  $p < 0.0001$ ;  $ST_1$  versus  $ST_2$ ,  $p = 0.6026$ ; **Figure 4B**) conditions. While visual sensitivity at the intermediate location was significantly lower than at the saccade target locations (BTW:  $d' = 0.6 \pm 0.2$  versus  $ST_1$ ,  $p < 0.0001$ ; BTW versus  $ST_2$ ,  $p < 0.0001$ ; **Figure 4B**), it was, however, slightly increased relative to the control locations in the  $30^\circ$  condition (BTW versus CTRL,  $p = 0.0010$ ).

In order to disentangle whether visual attention is obligatorily deployed at the endpoint of saccades, we analyzed visual sensitivity at all locations as a function of the saccade landing direction (see step 6.3 in the protocol). Crucially, the specific saccade landing distribution observed in the  $30^\circ$  condition of this protocol made it possible to analyze the deployment of visual attention before saccades associated with spatially distinct endpoints in response to identical visual input. More specifically, by analyzing visual sensitivity before averaging saccades, we could determine whether or not attention shifts towards the endpoint of saccades even when it does not spatially coincide with a saccade goal. We observed that visual sensitivity was significantly enhanced at the endpoint of accurate saccades in both the  $90^\circ$  ( $ST_{1+2}$  saccaded:  $d' = 3.0 \pm 0.4$  versus  $ST_{1+2}$  non-saccaded:  $d' = 1.7 \pm 0.4$ ,  $p < 0.0001$ ; **Figure 4E**) and the  $30^\circ$  ( $ST_{1+2}$  saccaded:  $d' = 2.7 \pm 0.4$  versus  $ST_{1+2}$  non-saccaded:  $d' = 2.0 \pm 0.3$ ,  $p = 0.0080$ ; **Figure 4F**) condition. In contrast, before averaging saccades, visual sensitivity was not enhanced at the saccade endpoint but slightly reduced (BTW saccaded:  $d' = 0.4 \pm 0.2$  versus BTW non-saccaded:  $d' = 0.7 \pm$

0.2,  $p < 0.0001$ ; **Figure 4F**). Thus, visual attention was not obligatorily shifted towards the endpoint of the upcoming saccade. Interestingly, averaging saccades were associated with an equal enhancement of visual sensitivity at the two surrounding saccade targets ( $ST_1$ :  $d' = 2.2 \pm 0.4$  versus  $ST_2$ :  $d' = 2.2 \pm 0.4$ ,  $p = 0.8402$ ; **Figure 4D**), suggesting that attentional selection among the saccade targets was not readily resolved before the onset of averaging saccades.

To further evaluate a potential correlate of attentional selection before averaging saccades, data were analyzed as a function of the landing direction of corrective saccades, which can be frequently observed upon the execution of averaging saccades. We did not observe a significant benefit at the endpoint of corrective saccades following an averaging saccade (corrective saccade directed towards  $ST_{1+2}$ :  $d' = 2.8 \pm 0.5$  versus corrective saccade not directed towards  $ST_{1+2}$ :  $d' = 2.5 \pm 0.8$ ,  $p = 0.68300$ ; **Figure 5C**), which supports the interpretation that attentional selection was not resolved before averaging saccades.

#### FIGURE AND TABLE LEGENDS:

**Figure 1. Instructions as presented to the participants.** Visualization of the experimental instructions as presented to the participants at the beginning of each block.

**Figure 2. Experimental procedure and normalized saccade landing frequency maps. A.** Stimulus timing and display. Participants prepared a saccade from the fixation target (FT) to one of the two potential saccade targets ( $ST_1$  and  $ST_2$ ), presented simultaneously at two randomly chosen stimulus streams with an inter-target angular distance of either  $90^\circ$  (top panels) or  $30^\circ$  (bottom panels). The saccade targets were either shown continuously ( $cST_{1+2}$ ) or transiently ( $tST_{1+2}$ ). Stimulus streams could either be distractor streams (DS), composed of alternating vertical Gabors and masks (40 Hz) or discrimination target streams (DTS) which included the presentation of a brief discrimination target (DT, 25 ms), a clockwise or counterclockwise tilted Gabor, shown between 75 and 175 ms after the saccade targets onset. Participants saccaded towards one of the saccade targets and had to report the orientation of the discrimination target, appearing randomly at one of the 24 stimulus stream locations. Note that stimuli are sketched in order to increase their visibility. Actual stimuli match those shown in the stimulus streams depiction. **B.** Normalized saccade landing frequency maps averaged across participants ( $n=10$ ) for the  $90^\circ$  (top) and  $30^\circ$  (bottom) conditions (collapsed across the transient and continuous ST presentation). This figure has been reprinted from Wollenberg *et al.* (2018)<sup>23</sup>.

**Figure 3. Saccade metrics. A-B.** Circular plots show the averaged frequency distribution of the saccade landing direction binned in evenly distributed angular sectors of  $5^\circ$ , in the  $90^\circ$  (A) and  $30^\circ$  conditions (B). Stimulus configuration is rotated as to align the two saccade targets symmetrically around the geometrical angle zero (see central insets). **C-D.** Bar graphs illustrate averaged frequency of trials as a function of the saccade landing direction binned in 24 evenly distributed angular sectors of  $15^\circ$ . Data are shown for the three positions of interest ( $ST_1$ , BTW and  $ST_2$ ) in the  $90^\circ$  (C) and  $30^\circ$  conditions (D). **E-H.** Averaged saccade latency (E, F) and amplitude (G, H) observed for the same three positions of interest in the  $90^\circ$  (E, G) and  $30^\circ$  conditions (F, H). All data are shown irrespective of the duration (continuously or transiently) of the saccade

targets. Light gray areas and error bars represent SEM. Polar plot black lines and corresponding light gray areas show linear interpolation between data points. This figure has been reprinted from Wollenberg *et al.* (2018)<sup>23</sup>.

**Figure 4. Visual sensitivity. A-B.** Circular plots show averaged visual sensitivity ( $d'$ ) as a function of the DT position in the 90° (A) and 30° conditions (B), irrespective of the duration of the saccade targets and across all saccade directions observed. Bar graphs illustrate visual sensitivity for four positions of interest (ST<sub>1</sub>, BTW, ST<sub>2</sub>, CTRL). **C-D.** Visual sensitivity as a function of the DT position relative to the saccade landing direction in the 90° (C) and 30° conditions (D), irrespective of the duration of the saccade targets (blue: saccade to ST<sub>1</sub>; green: saccade to BTW; red: saccade to ST<sub>2</sub>). For each saccade direction, we took the average sensitivity for each discrimination target location. For example, the blue line plots visual sensitivity when saccades were made towards ST<sub>1</sub> and the discrimination target was either at ST<sub>1</sub> (+15° on the polar plot), BTW (15° counterclockwise to ST<sub>1</sub>; 0° on the polar plot) or ST<sub>2</sub> (30° counterclockwise to ST<sub>1</sub>; + 345° on the polar plot), and so on. **E-F.** Bar graphs illustrate sensitivity observed for DT shown at the saccaded (purple: e.g., DT at ST<sub>1</sub> and saccade to ST<sub>1</sub>) and the non-saccaded positions (light-purple: e.g. DT at ST<sub>1</sub> and saccade to ST<sub>2</sub> or BTW) in the 90° (E) and the 30° (F) conditions. Conventions are as in **Figure 3**. This figure has been reprinted from Wollenberg *et al.* (2018)<sup>23</sup>.

**Figure 5. Corrective saccades. A.** Circular plot shows averaged frequency distribution of the corrective saccade landing direction following an averaging saccade. **B.** The bar graph illustrates averaged frequency of trials as a function of the corrective saccade landing direction following an averaging saccade for three positions of interest (ST<sub>1</sub>, BTW and ST<sub>2</sub>). **C.** The bar graph illustrates visual sensitivity as a function of the direction of the first corrective saccade for all trials in which an averaging saccade was executed. Purple bars show visual sensitivity for trials in which the corrective saccade was directed towards the location at which the DT appeared (e.g. DT at ST<sub>1</sub> and corrective saccade towards ST<sub>1</sub>). Light purple bars show visual sensitivity for trials in which the corrective saccade was directed towards a different location than the location at which the DT appeared (e.g. DT at ST<sub>1</sub> and corrective saccade towards ST<sub>2</sub> or BTW). Conventions are as in **Figure 3-4**. This figure has been reprinted from Wollenberg *et al.* (2018)<sup>23</sup>.

## DISCUSSION:

This experimental protocol employed the concurrent assessment of gaze behavior and presaccadic visual sensitivity in a free choice saccade task. It allowed us to analyze whether visual attention is indeed obligatorily coupled to oculomotor programming at the behavioral level and therefore systematically deployed at the endpoint of saccades. Two saccade targets were presented in the close proximity (30°) on half of the trials in which we observed a distinct global effect, reflected in a saccade landing distribution consisting of both, accurate and averaging saccades. To conclude on the spatial coupling between visual attention and the saccadic endpoint, visual sensitivity was analyzed and compared across different locations as a function of the saccade landing direction. While we observed a consistent and selective enhancement of visual sensitivity at the endpoint of accurate saccades, visual sensitivity was not enhanced at the endpoint of averaging saccades. Rather, visual sensitivity was equally facilitated at the two saccade targets before the execution of averaging saccades, suggesting that saccade averaging

arises from unresolved attentional selection among the saccade targets. Our results, therefore, demonstrate that visual attention is not obligatorily deployed at the endpoint of the executed oculomotor program. A corrective saccade analysis, which demonstrated that the even deployment of visual sensitivity across two saccade targets before averaging saccades did not systematically vary as a function the corrective saccade direction, further confirmed this interpretation. In this regard, our data are consistent with a recent model by Zirnsak *et al.*<sup>25</sup> which assumes a target selection process that gradually builds up over time.

Importantly, our protocol differs from other behavioral studies that reported evidence for a dissociation between attention and saccades in several aspects. While some studies based their conclusion on saccadic reaction times<sup>14,15,16</sup>, we used a direct measure of visual spatial attention, namely visual sensitivity during saccade preparation. The specific parameters used throughout this protocol were effective in replicating the classical presaccadic shift of attention<sup>8,9</sup> as evident in the consistent enhancement of visual sensitivity at the endpoint of accurate saccades. Thus, the protocol allowed for reliable detection of systematic modulations of visual attention specific to saccade preparation. This is an important prerequisite to validly interpret presaccadic attentional effects, and in particular, the observed absence of attentional enhancement at the endpoint of averaging saccades.

A central and distinct aspect of this protocol was the random presentation of the discrimination target among various locations. Thereby, we could sample visual sensitivity across the entire visual field, which consequently allowed us to not only determine whether attention is facilitated at the endpoint of saccades but also to investigate the spread of attention around this area including adjacent locations. The discrete allocation of attention at the two saccade targets (limited to less than  $\sim 2.6^\circ$ , the distance between two of our adjacent stimuli) we observed before averaging saccades contradicts an early account which suggested that averaging saccades may reflect a coarse processing of the visual scene<sup>17</sup> and argues for an enhancement of local rather than global visual information processing. Further, the random presentation of the discrimination target rendered its location completely unpredictable to participants. Thus, our protocol generally facilitated an even deployment of visual attention across the visual field with respect to the discrimination task. We consider this fact important with regard to any potential attentional effects and conclusions related to saccade preparation.

However, since eye movements are not typically performed while trying to discriminate stimuli across the entire visual field in natural vision, the results obtained in this protocol can not unrestrictedly account for oculomotor behavior in every day life. Furthermore, the oculomotor task did inevitably bias the deployment of attention via the saccade target cueing. The saccade targets did not only introduce relevant oculomotor goals but also salient exogenous cues that likely attracted attention. Thus, it is possible that visual discrimination performance at the intermediate location was generally deteriorated due to some masking elicited by the two surrounding saccade targets. In order to decrease the impact of the saccade targets with respect to discrimination performance at the intermediate location and to evaluate potential masking effects, we decided to present the saccade targets only transiently (for 50 ms) instead of continuously (until the trial end) on half of the trials. Consequently, even though both cueing

conditions introduced visual onsets at the saccade target locations, the saccade targets had always disappeared before the onset of the discrimination target in the transient cueing condition. While the majority of results were very consistent across both cueing conditions and were therefore combined in the final analysis, we indeed observed an indication of a masking effect in the continuous cueing condition relative to the transient cueing condition. Overall, irrespective of the saccade direction, visual sensitivity at the intermediate location was slightly decreased in the continuous compared to the transient cueing condition. Given the notion that transient saccade target cueing apparently minimizes masking of the intermediate location while still being effective in eliciting averaging saccades, future studies using a protocol similar to ours should consider employing transient cueing of targets. Despite our efforts to minimize masking effects via the transient cueing of targets, we can not rule out that the transient cueing still introduced a forward masking effect, which might potentially account for the poor discrimination performance at the intermediate location to some extent.

Taken together, our protocol allowed to directly address the coupling between visual attention and oculomotor programming, and to reveal a distinct spatial dissociation between attention and the endpoint of averaging saccades at the behavioral level. Our results argue against a mandatory coupling between visual attention and oculomotor programming suggested in the premotor theory of attention. Future studies should employ paradigms including concurrent neurophysiological recordings within areas such as the FEF and SC to further resolve the coupling between visual attention and oculomotor programming.

#### **ACKNOWLEDGMENTS:**

This research was supported by grants of the Deutsche Forschungsgemeinschaft to H.D. (DE336/5-1 and RTG 2175 "Perception in context and its neural basis") and to M.S. (SZ343/1) and a Marie Skłodowska-Curie Action Individual Fellowship to M.S. (704537).

#### **DISCLOSURES:**

The authors have declared that no competing interests exist.

#### **REFERENCES:**

1. Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. Reorienting attention across the horizontal and vertical meridians: evidence in favor of a premotor theory of attention. *Neuropsychologia*. 25(1), 31-40, (1997).
2. Rizzolatti, G., Riggio, L., & Sheliga, B. M. Space and selective attention. *Attention and performance XV*. 15, 231-265, (1994)
3. Corbetta, M. Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proceedings of the National Academy of Sciences*. 95(3), 831-838, (1998).
4. Müller, J. R., Philiastides, M. G., & Newsome, W. T. Microstimulation of the superior colliculus focuses attention without moving the eyes. *Proceedings of the National Academy of Sciences*. 102(3), 524-529, (2005).
5. McPeck, R. M., & Keller, E. L. Deficits in saccade target selection after inactivation of superior colliculus. *Nature neuroscience*. 7(7), 757, (2004).

- 529 6. Moore, T., & Armstrong, K. M. Selective gating of visual signals by microstimulation of  
530 frontal cortex. *Nature*. 421(6921), 370, (2003).
- 531 7. Moore, T., & Fallah, M. Microstimulation of the frontal eye field and its effects on covert  
532 spatial attention. *Journal of neurophysiology*. 91(1), 152-162, (2004).
- 533 8. Kowler, E., Anderson, E., Doshier, B., & Blaser, E. The role of attention in the programming  
534 of saccades. *Vision research*. 35(13), 1897-1916, (1995).
- 535 9. Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition:  
536 Evidence for a common attentional mechanism. *Vision research*. 36(12), 1827-1837, (1996).
- 537 10. Thompson, K. G., Biscoe, K. L., & Sato, T. R. Neuronal basis of covert spatial attention in  
538 the frontal eye field. *Journal of Neuroscience*. 25(41), 9479-9487, (2005).
- 539 11. Ignashchenkova, A., Dicke, P. W., Haarmeier, T., & Thier, P. Neuron-specific contribution  
540 of the superior colliculus to overt and covert shifts of attention. *Nature neuroscience*. 7(1), 56,  
541 (2004).
- 542 12. Gregoriou, G. G., Gotts, S. J., & Desimone, R. Cell-type-specific synchronization of neural  
543 activity in FEF with V4 during attention. *Neuron*. 73(3), 581-594, (2012).
- 544 13. Born, S., Mottet, I., & Kerzel, D. Presaccadic perceptual facilitation effects depend on  
545 saccade execution: Evidence from the stop-signal paradigm. *Journal of Vision*. 14(3), 7-7, (2014).
- 546 14. Belopolsky, A. V., & Theeuwes, J. (2012). Updating the premotor theory: the allocation of  
547 attention is not always accompanied by saccade preparation. *Journal of Experimental Psychology:*  
548 *Human Perception and Performance*. 38(4), 902, (2012).
- 549 15. Hunt, A. R., & Kingstone, A. Covert and overt voluntary attention: linked or independent?  
550 *Cognitive Brain Research*. 18(1), 102-105, (2003).
- 551 16. Smith, D. T., Schenk, T., & Rorden, C. Saccade preparation is required for exogenous  
552 attention but not endogenous attention or IOR. *Journal of Experimental Psychology: Human*  
553 *Perception and Performance*. 38(6), 1438, (2012).
- 554 17. Findlay, J. M. Global visual processing for saccadic eye movements. *Vision research*. 22(8),  
555 1033-1045, (1982).
- 556 18. Coren, S., & Hoenig, P. Effect of non-target stimuli upon length of voluntary saccades.  
557 *Perceptual and motor skills*, 34(2), 499-508, (1972).
- 558 19. Van der Stigchel, S., & Nijboer, T. C. The global effect: what determines where the eyes  
559 land?. *Journal of Eye Movement Research*. 4(2), (2011).
- 560 20. Vitu, F. About the global effect and the critical role of retinal eccentricity: Implications for  
561 eye movements in reading. *Journal of Eye Movement Research*. 2(3), (2008).
- 562 21. Hanning, N., Deubel, H., & Szinte, M. Sensitivity measures of visuospatial attention. *Journal*  
563 *of Vision*. 17(10), 673-673, (2017).
- 564 22. Van der Stigchel, S., & De Vries, J. P. There is no attentional global effect: Attentional shifts  
565 are independent of the saccade endpoint. *Journal of vision*. 15(15), 17-17, (2015).
- 566 23. Wollenberg, L., Deubel, H., & Szinte, M. Visual attention is not deployed at the endpoint  
567 of averaging saccades. *PLoS biology*. 16(6), e2006548, (2018).
- 568 24. Engbert, R., & Mergenthaler, K. Microsaccades are triggered by low retinal image slip.  
569 *Proceedings of the National Academy of Sciences*. 103(18), 7192-7197, (2006).  
570 doi:10.1073/pnas.0509557103
- 571 25. Zirnsak, M., Beuth, F., & Hamker, F. H. Split of spatial attention as predicted by a systems-  
572 level model of visual attention. *European Journal of Neuroscience*. 33(11), 2035-2045, (2011).

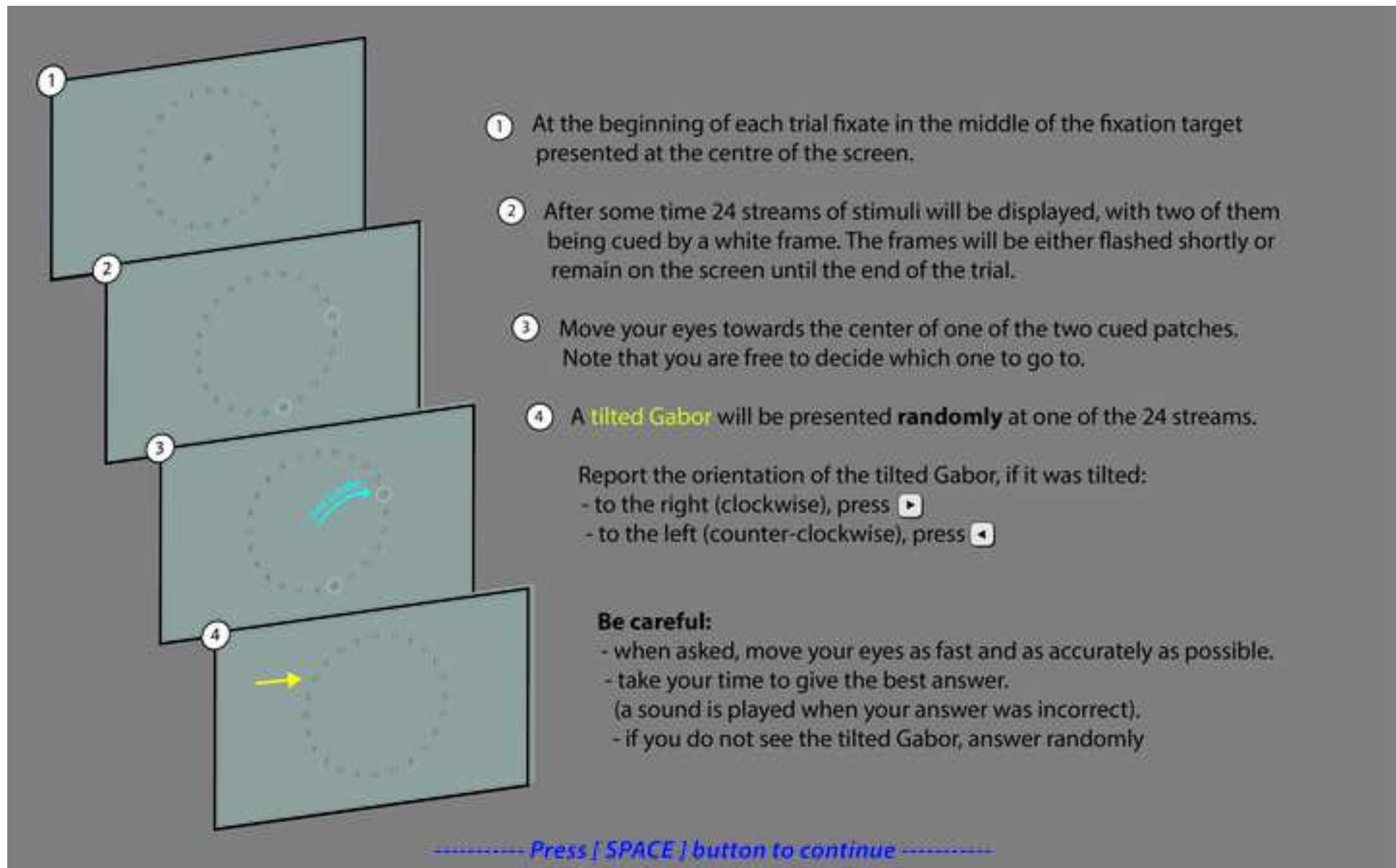




Figure 2

[Click here to access/download;Figure;Figure 2.tif](#)

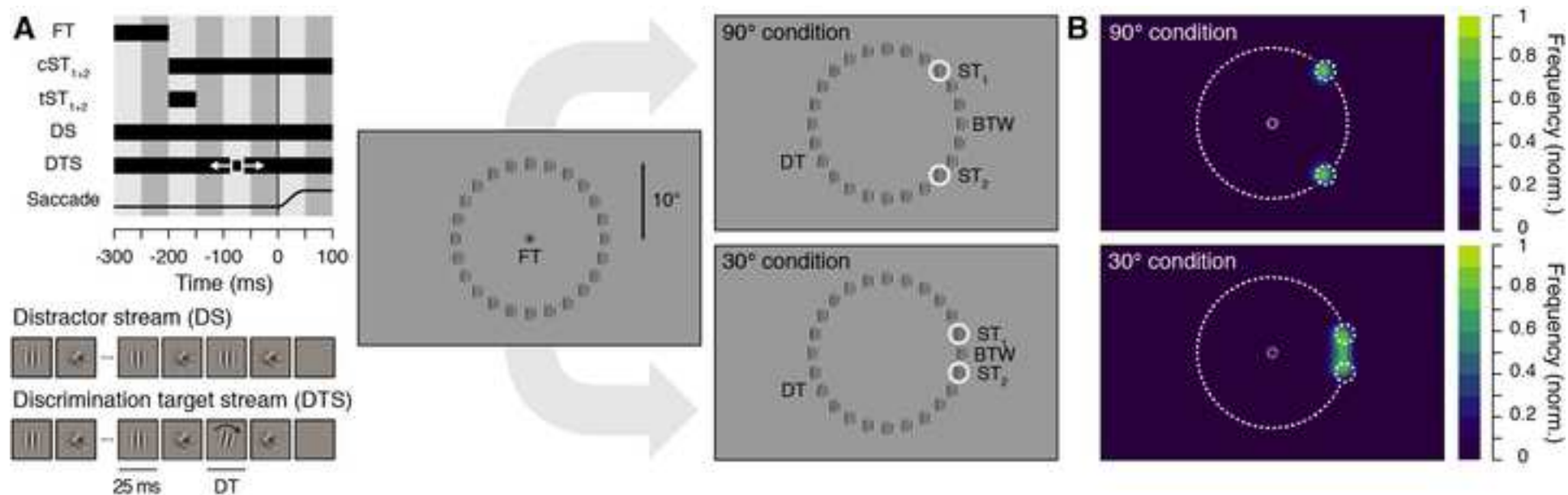


Figure 3

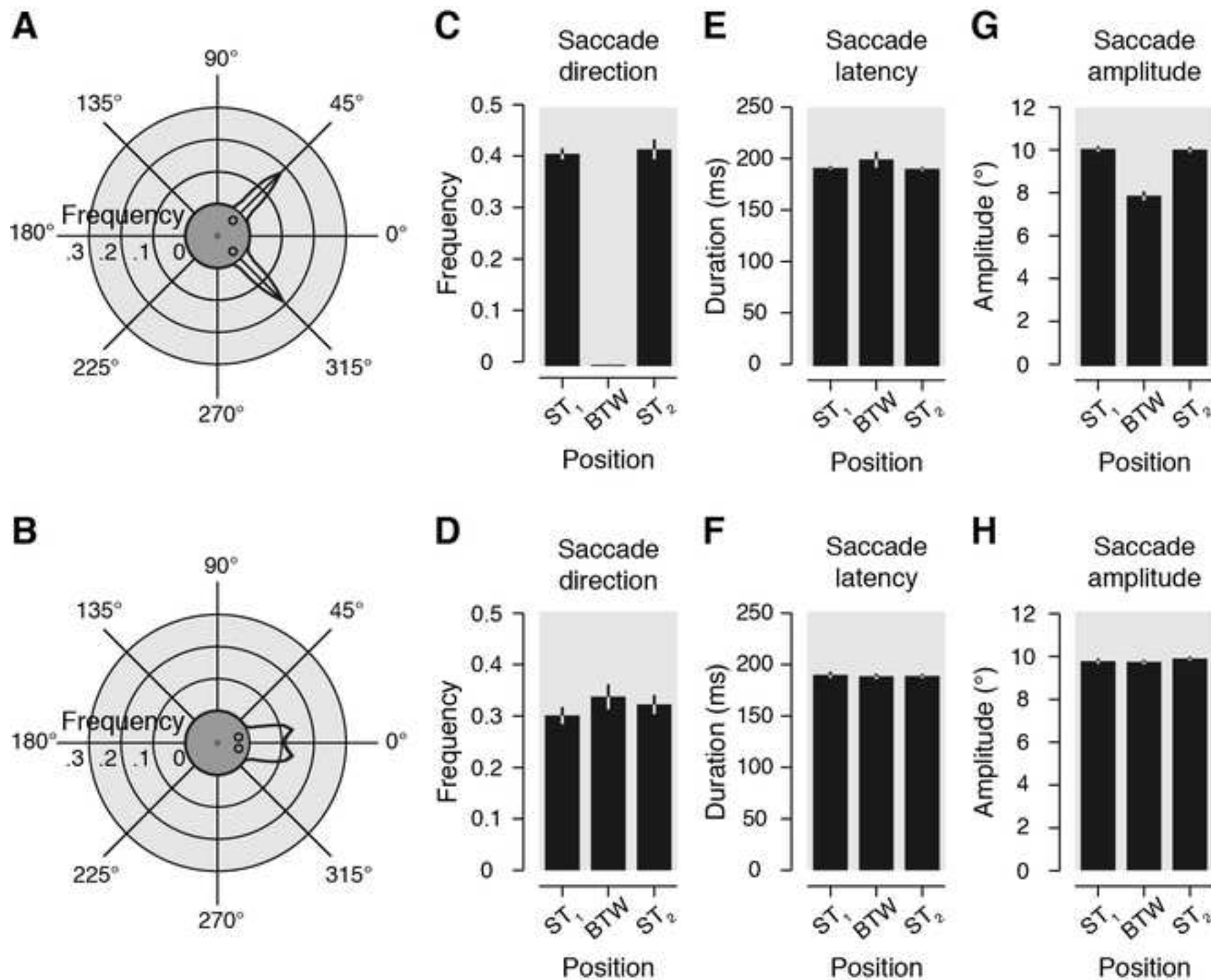
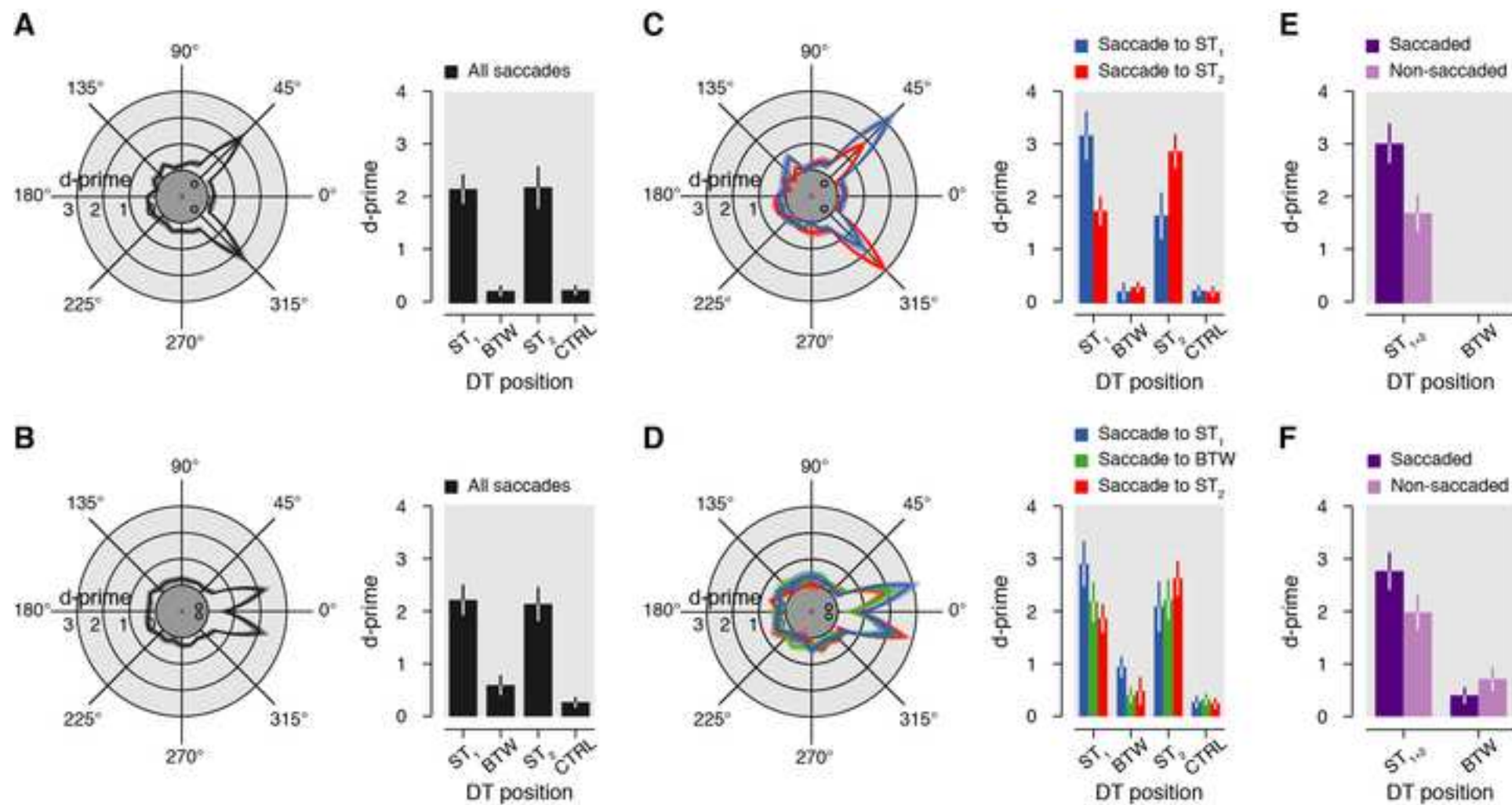
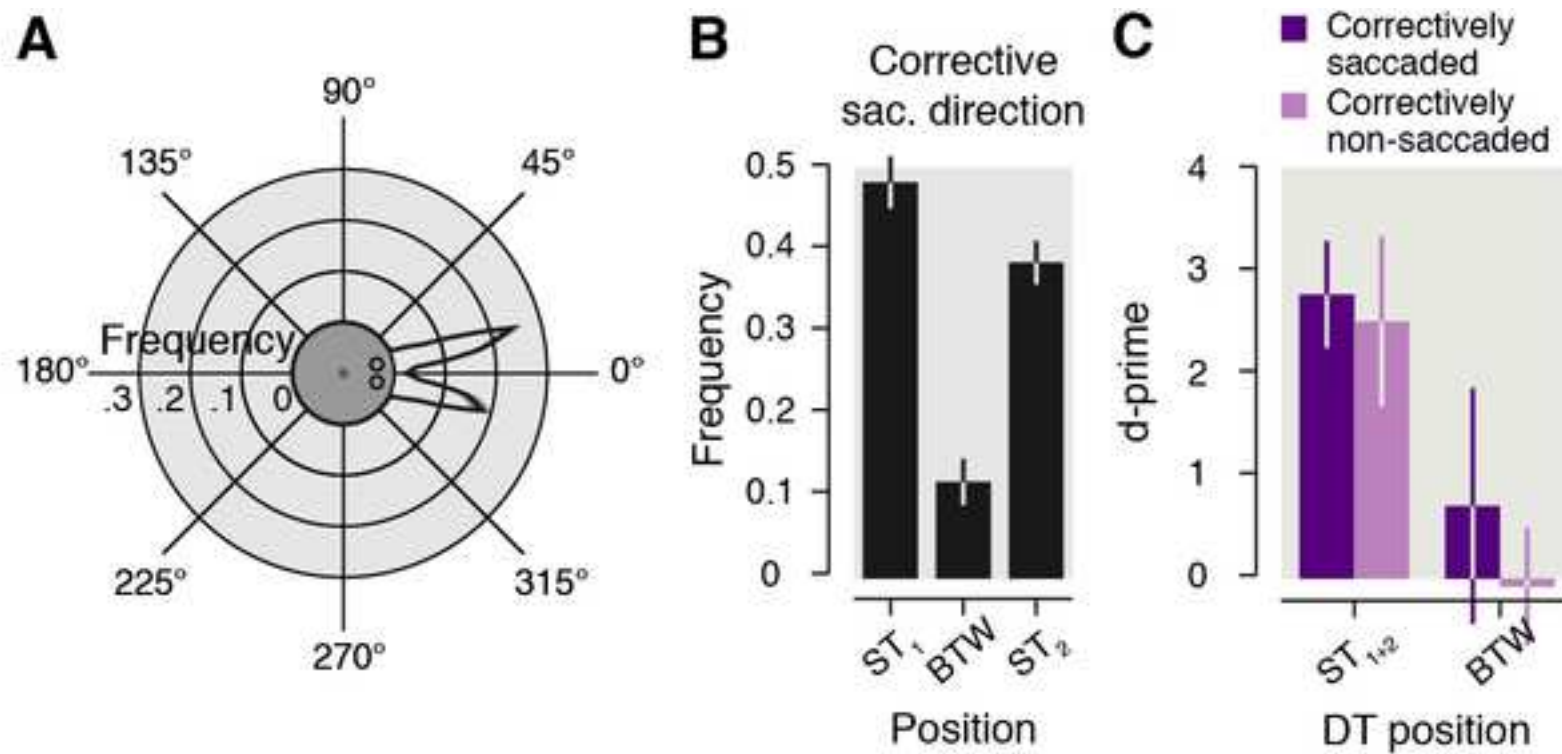


Figure 4

[Click here to access/download;Figure;Figure 4.tif](#)





Name of Material/ Equipment	Company
Computer	Apple iMac (Cupertino, CA)
CRT Screen	Sony GDM F900 (Tokyo, Japan)
Eye Tracker	EyeLink 1000 Desktop Mount (SR Research, Osgoode, Ontario, Canada)
Software	Matlab (The MathWorks, Natick, MA) / toolboxes: Psychophics, EyeLink

**Catalog Number**

**Comments/Description**

24 inch screen with a spatial resolution of 1024 x 640 pixels and a vertical refresh rate of 120 Hz operating at a sampling rate of 1 kHz

## ARTICLE AND VIDEO LICENSE AGREEMENT

Title of Article:	Eye Tracking and Presaccadic Assessment of Visual Spatial Attention: Revealing the Deployment of Visual Attention Before Accurate and Averaging Saccades in a Combined Oculomotor and Visual Discrimination Task
Author(s):	Luca Wollenberg, Heiner Deubel, Martin Szinte

Item 1: The Author elects to have the Materials be made available (as described at <http://www.jove.com/publish>) via:

☐ Standard Access ☒ Open Access

Item 2: Please select one of the following items:

- ☒ The Author is **NOT** a United States government employee.
- ☐ The Author is a United States government employee and the Materials were prepared in the course of his or her duties as a United States government employee.
- ☐ The Author is a United States government employee but the Materials were NOT prepared in the course of his or her duties as a United States government employee.

### ARTICLE AND VIDEO LICENSE AGREEMENT

1. **Defined Terms.** As used in this Article and Video License Agreement, the following terms shall have the following meanings: “**Agreement**” means this Article and Video License Agreement; “**Article**” means the article specified on the last page of this Agreement, including any associated materials such as texts, figures, tables, artwork, abstracts, or summaries contained therein; “**Author**” means the author who is a signatory to this Agreement; “**Collective Work**” means a work, such as a periodical issue, anthology or encyclopedia, in which the Materials in their entirety in unmodified form, along with a number of other contributions, constituting separate and independent works in themselves, are assembled into a collective whole; “**CRC License**” means the Creative Commons Attribution-Non Commercial-No Derivs 3.0 Unported Agreement, the terms and conditions of which can be found at: <http://creativecommons.org/licenses/by-nc-nd/3.0/legalcode>; “**Derivative Work**” means a work based upon the Materials or upon the Materials and other pre-existing works, such as a translation, musical arrangement, dramatization, fictionalization, motion picture version, sound recording, art reproduction, abridgment, condensation, or any other form in which the Materials may be recast, transformed, or adapted; “**Institution**” means the institution, listed on the last page of this Agreement, by which the Author was employed at the time of the creation of the Materials; “**JoVE**” means MyJoVE Corporation, a Massachusetts corporation and the publisher of The Journal of Visualized Experiments; “**Materials**” means the Article and / or the Video; “**Parties**” means the Author and JoVE; “**Video**” means any video(s) made by the Author, alone or in conjunction with any other parties, or by JoVE or its affiliates or agents, individually or in collaboration with the Author or any other parties, incorporating all or any portion

of the Article, and in which the Author may or may not appear.

2. **Background.** The Author, who is the author of the Article, in order to ensure the dissemination and protection of the Article, desires to have the JoVE publish the Article and create and transmit videos based on the Article. In furtherance of such goals, the Parties desire to memorialize in this Agreement the respective rights of each Party in and to the Article and the Video.

3. **Grant of Rights in Article.** In consideration of JoVE agreeing to publish the Article, the Author hereby grants to JoVE, subject to **Sections 4** and **7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Article in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Article into other languages, create adaptations, summaries or extracts of the Article or other Derivative Works (including, without limitation, the Video) or Collective Works based on all or any portion of the Article and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and (c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. If the “Open Access” box has been checked in **Item 1** above, JoVE and the Author hereby grant to the public all such rights in the Article as provided in, but subject to all limitations and requirements set forth in, the CRC License.



## ARTICLE AND VIDEO LICENSE AGREEMENT

4. **Retention of Rights in Article.** Notwithstanding the exclusive license granted to JoVE in **Section 3** above, the Author shall, with respect to the Article, retain the non-exclusive right to use all or part of the Article for the non-commercial purpose of giving lectures, presentations or teaching classes, and to post a copy of the Article on the Institution's website or the Author's personal website, in each case provided that a link to the Article on the JoVE website is provided and notice of JoVE's copyright in the Article is included. All non-copyright intellectual property rights in and to the Article, such as patent rights, shall remain with the Author.

5. **Grant of Rights in Video – Standard Access.** This **Section 5** applies if the "Standard Access" box has been checked in **Item 1** above or if no box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby acknowledges and agrees that, Subject to **Section 7** below, JoVE is and shall be the sole and exclusive owner of all rights of any nature, including, without limitation, all copyrights, in and to the Video. To the extent that, by law, the Author is deemed, now or at any time in the future, to have any rights of any nature in or to the Video, the Author hereby disclaims all such rights and transfers all such rights to JoVE.

6. **Grant of Rights in Video – Open Access.** This **Section 6** applies only if the "Open Access" box has been checked in **Item 1** above. In consideration of JoVE agreeing to produce, display or otherwise assist with the Video, the Author hereby grants to JoVE, subject to **Section 7** below, the exclusive, royalty-free, perpetual (for the full term of copyright in the Article, including any extensions thereto) license (a) to publish, reproduce, distribute, display and store the Video in all forms, formats and media whether now known or hereafter developed (including without limitation in print, digital and electronic form) throughout the world, (b) to translate the Video into other languages, create adaptations, summaries or extracts of the Video or other Derivative Works or Collective Works based on all or any portion of the Video and exercise all of the rights set forth in (a) above in such translations, adaptations, summaries, extracts, Derivative Works or Collective Works and (c) to license others to do any or all of the above. The foregoing rights may be exercised in all media and formats, whether now known or hereafter devised, and include the right to make such modifications as are technically necessary to exercise the rights in other media and formats. For any Video to which this **Section 6** is applicable, JoVE and the Author hereby grant to the public all such rights in the Video as provided in, but subject to all limitations and requirements set forth in, the CRC License.

7. **Government Employees.** If the Author is a United States government employee and the Article was prepared in the course of his or her duties as a United States government employee, as indicated in **Item 2** above, and any of the licenses or grants granted by the Author hereunder exceed the scope of the 17 U.S.C. 403, then the rights granted hereunder shall be limited to the maximum

rights permitted under such statute. In such case, all provisions contained herein that are not in conflict with such statute shall remain in full force and effect, and all provisions contained herein that do so conflict shall be deemed to be amended so as to provide to JoVE the maximum rights permissible within such statute.

8. **Protection of the Work.** The Author(s) authorize JoVE to take steps in the Author(s) name and on their behalf if JoVE believes some third party could be infringing or might infringe the copyright of either the Author's Article and/or Video.

9. **Likeness, Privacy, Personality.** The Author hereby grants JoVE the right to use the Author's name, voice, likeness, picture, photograph, image, biography and performance in any way, commercial or otherwise, in connection with the Materials and the sale, promotion and distribution thereof. The Author hereby waives any and all rights he or she may have, relating to his or her appearance in the Video or otherwise relating to the Materials, under all applicable privacy, likeness, personality or similar laws.

10. **Author Warranties.** The Author represents and warrants that the Article is original, that it has not been published, that the copyright interest is owned by the Author (or, if more than one author is listed at the beginning of this Agreement, by such authors collectively) and has not been assigned, licensed, or otherwise transferred to any other party. The Author represents and warrants that the author(s) listed at the top of this Agreement are the only authors of the Materials. If more than one author is listed at the top of this Agreement and if any such author has not entered into a separate Article and Video License Agreement with JoVE relating to the Materials, the Author represents and warrants that the Author has been authorized by each of the other such authors to execute this Agreement on his or her behalf and to bind him or her with respect to the terms of this Agreement as if each of them had been a party hereto as an Author. The Author warrants that the use, reproduction, distribution, public or private performance or display, and/or modification of all or any portion of the Materials does not and will not violate, infringe and/or misappropriate the patent, trademark, intellectual property or other rights of any third party. The Author represents and warrants that it has and will continue to comply with all government, institutional and other regulations, including, without limitation all institutional, laboratory, hospital, ethical, human and animal treatment, privacy, and all other rules, regulations, laws, procedures or guidelines, applicable to the Materials, and that all research involving human and animal subjects has been approved by the Author's relevant institutional review board.

11. **JoVE Discretion.** If the Author requests the assistance of JoVE in producing the Video in the Author's facility, the Author shall ensure that the presence of JoVE employees, agents or independent contractors is in accordance with the relevant regulations of the Author's institution. If more than one author is listed at the beginning of this Agreement, JoVE may, in its sole



## ARTICLE AND VIDEO LICENSE AGREEMENT

discretion, elect not take any action with respect to the Article until such time as it has received complete, executed Article and Video License Agreements from each such author. JoVE reserves the right, in its absolute and sole discretion and without giving any reason therefore, to accept or decline any work submitted to JoVE. JoVE and its employees, agents and independent contractors shall have full, unfettered access to the facilities of the Author or of the Author's institution as necessary to make the Video, whether actually published or not. JoVE has sole discretion as to the method of making and publishing the Materials, including, without limitation, to all decisions regarding editing, lighting, filming, timing of publication, if any, length, quality, content and the like.

**12. Indemnification.** The Author agrees to indemnify JoVE and/or its successors and assigns from and against any and all claims, costs, and expenses, including attorney's fees, arising out of any breach of any warranty or other representations contained herein. The Author further agrees to indemnify and hold harmless JoVE from and against any and all claims, costs, and expenses, including attorney's fees, resulting from the breach by the Author of any representation or warranty contained herein or from allegations or instances of violation of intellectual property rights, damage to the Author's or the Author's institution's facilities, fraud, libel, defamation, research, equipment, experiments, property damage, personal injury, violations of institutional, laboratory, hospital, ethical, human and animal treatment, privacy or other rules, regulations, laws, procedures or guidelines, liabilities and other losses or damages related in any way to the submission of work to JoVE, making of videos by JoVE, or publication in JoVE or elsewhere by JoVE. The Author shall be responsible for, and shall hold JoVE harmless from, damages caused by lack of sterilization, lack of cleanliness or by contamination due to

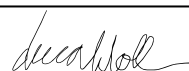
the making of a video by JoVE its employees, agents or independent contractors. All sterilization, cleanliness or decontamination procedures shall be solely the responsibility of the Author and shall be undertaken at the Author's expense. All indemnifications provided herein shall include JoVE's attorney's fees and costs related to said losses or damages. Such indemnification and holding harmless shall include such losses or damages incurred by, or in connection with, acts or omissions of JoVE, its employees, agents or independent contractors.

**13. Fees.** To cover the cost incurred for publication, JoVE must receive payment before production and publication of the Materials. Payment is due in 21 days of invoice. Should the Materials not be published due to an editorial or production decision, these funds will be returned to the Author. Withdrawal by the Author of any submitted Materials after final peer review approval will result in a US\$1,200 fee to cover pre-production expenses incurred by JoVE. If payment is not received by the completion of filming, production and publication of the Materials will be suspended until payment is received.

**14. Transfer, Governing Law.** This Agreement may be assigned by JoVE and shall inure to the benefits of any of JoVE's successors and assignees. This Agreement shall be governed and construed by the internal laws of the Commonwealth of Massachusetts without giving effect to any conflict of law provision thereunder. This Agreement may be executed in counterparts, each of which shall be deemed an original, but all of which together shall be deemed to be one and the same agreement. A signed copy of this Agreement delivered by facsimile, e-mail or other means of electronic transmission shall be deemed to have the same legal effect as delivery of an original signed copy of this Agreement.

A signed copy of this document must be sent with all new submissions. Only one Agreement is required per submission.

### CORRESPONDING AUTHOR

Name:	Luca Wollenberg	
Department:	General and Experimental Psychology	
Institution:	Ludwig-Maximilians-Universität München	
Title:		
Signature:		Date: 09.26.2018

Please submit a **signed** and **dated** copy of this license by one of the following three methods:

1. Upload an electronic version on the JoVE submission site
2. Fax the document to +1.866.381.2236
3. Mail the document to JoVE / Attn: JoVE Editorial / 1 Alewife Center #200 / Cambridge, MA 02140

Your manuscript, JoVE59162R1 "Eye Tracking and Presaccadic Assessment of Visual Sensitivity: Revealing the Deployment of Visual Attention Before Accurate and Averaging Saccades," has been editorially reviewed and the following comments need to be addressed. Please track the changes to identify all of the manuscript edits. After revising the submission, please also upload a separate document that addresses each of the editorial comments individually with the revised manuscript.

1. The editor has formatted the manuscript to match the journal's style, Please retain the same.

The formatting of the manuscript has been retained.

2. Please address all specific comments marked in the manuscript.

All the specific comments have been addressed (see tracked changes) and replied to (see replies to the editorial comments) in the revised manuscript.

3. Once done, please proofread the manuscript for any grammar or spelling issues.

The revised manuscript has been again processed for any grammar or spelling issues.

4. Please ensure that the highlighted steps are no more than 2.75 pages including headings and spacings.

The protocol has been processed to be no more than 2.75 pages of highlighted text.

The copyright permission to reuse figures from our previous publication is specified in the journal (PLOS Biology) policies (open access under the terms of Creative Commons Attribution License) as well as in the online publication itself:

- <https://journals.plos.org/plosbiology/s/accepted-manuscripts>
- <https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.2006548>

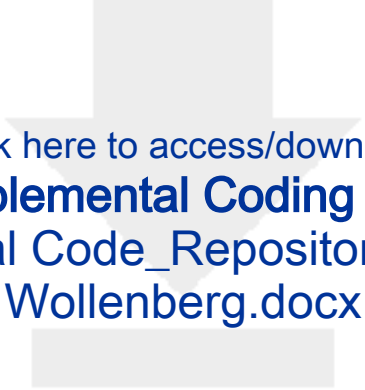


[Click here to access/download](#)

**Supplemental Coding Files**

Video\_Exemplary Trial\_Luca Wollenberg.mp4





[Click here to access/download](#)

**Supplemental Coding Files**

Experimental Code\_Repository Link\_Luca  
Wollenberg.docx

