Amplitude Changes in Response to Target Displacements During Monkey Eye-Head Movements

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Introduction

With the head restrained, changes in saccade amplitude can be produced by displacing a visual target during a saccade (McLaughlin, 1967). This form of saccadic adaptation has been described extensively in both humans and monkeys (Hopps & Fuchs, 2004). We investigated the effects on gaze, eye, and head movement amplitudes when targets were displaced during large amplitude horizontal gaze shifts made by head-unrestrained monkey subjects during the McLaughlin paradigm.

Methods

SUBJECTS: Three juvenile female rhesus monkeys (P,Q,S) participated in this study.

EXPERIMENTAL APPARATUS AND MEASURES:

- **Test Chamber**: darkened room, spherical presentation screen or LED Board
- **Subject Orientation:** Subjects sat upright in a primate chair and were free to move their eyes and head; however, movements of the torso were limited to ±5°.
- **Visual Targets & Presentation:** Targets were either computer-controlled green laser spots presented on the spherical presentation screen or red LEDs.
- **Measurements**: Eye and head movements were monitored using search coils (Judge et al. 1980; Freedman & Sparks, 1997). Three LEDs were mounted on top of the head coil/juice tube apparatus. These lasers were used to elicit different orbital eye positions at gaze onset (IEP).
- **TRIAL TYPES:**

Each trial type (Figure 1A-C) began with the illumination of ***one*** of the three head mounted LEDs. Subjects were required to align this head laser and fixate a stationary target (T_0). Following a fixation period (250-750ms), a second target (T_1) was illuminated at another spatial location. The subject was required to maintain head and gaze position within computer defined windows for 250-1250ms ("delay period"). If both these criterion were met, the head laser and T_0 were extinguished and the subject was allowed to shift the line of sight towards T_1. T_1 remained illuminated throughout "delayed" trials. In "probe" and "Adapt-Probe" trials T_1 was turned off after the gaze position signal had moved out of a computer defined window centered on the T_0 location. After the same criterion was met in "adaptation" trials (Fig 1E), the T_1 target was extinguished a new target (T_2) was illuminated either further away ("Forward Adaptation" Fig. 1C) or closer to ("Backward Adaptation", Fig. 1C) the initial fixation point (T_0). Subjects were rewarded for maintaining gaze position within a computer defined window either centered on T1 (delayed & probe trials; Fig1D) or centered halfway between T1 and T2 (Fig1E & F).

- **Target Locations:**

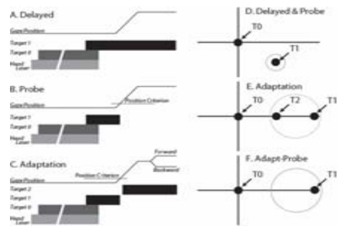
Delayed & Probe Trials: 8-10 T1 locations were chosen along various vectors originating from T0. This included the T_2 used during adaptation trials.

Backward Adaptation Trials: T1 = T0±50°
T2 = T0±25 or 26°

Forward Adaptation Trials: T1 = T0± 25 or 26°
T2 = T0±50°

Adapt Probe Trials: T1 target used during adaptation trials.

Figure 1: Trial Types & Reward Windows



DATA ANALYSIS:

•During adaptation and probe trials, the beginning and end of each ***primary*** Gaze, Eye, and Head movement were marked using a velocity criterion.

•Average primary Gaze, Saccade, Head Contribution, and Total Head movement amplitudes were calculated using all pre-adaptation probe trials (pre-adaptation mean) , the last 15 adaptation trials (post-adaptation mean) and the first 15 probe trials during post probe period (post-adaptation probe mean). The difference between pre-adaptation and post means were calculated using these values.

•Statistical significance was determined using t-tests ($p<0.05$) .

Eyes and Head Aligned (Centered Initial Eye Position)

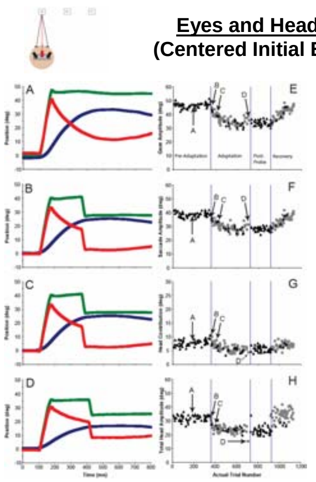


Figure 2. A-D: Gaze (green), eye (red), and head (blue) positions as functions of time during a backward adaptation session (Q1) in which the eyes were initially centered in the orbits (±5°). Each panel illustrates a gaze shift made a a different stage of the adaptation process. E-H: Gaze, saccade, head contribution and total head amplitudes of the primary gaze shifts made during pre-adaptation, adaptation, post-probe, and recovery segments of experiment Q1. Individual examples A-C are indicated with labeled arrows. Black triangles = adapt probe trials; Gray squares = Adaptation trials

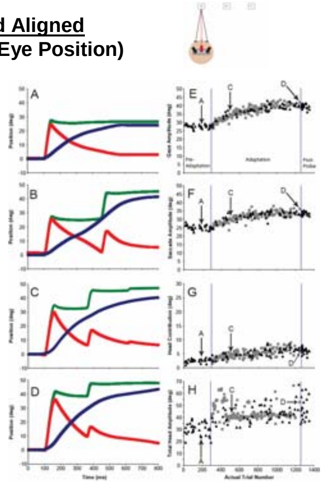


Figure 3. Gaze (green), eye (red), and head (blue) positions as functions of time during a forward adaptation session (Q3) in which the eyes were initially centered in the orbits (±5°). Each panel illustrates a gaze shift made a a different stage of the adaptation process. E-H: Gaze, saccade, head contribution and total head amplitudes of the primary gaze shifts made during pre-adaptation, adaptation, post-probe, and recovery segments of experiment Q3. Individual examples A-C are indicated with labeled arrows. Black triangles = adapt probe trials; Gray squares = Adaptation trials.

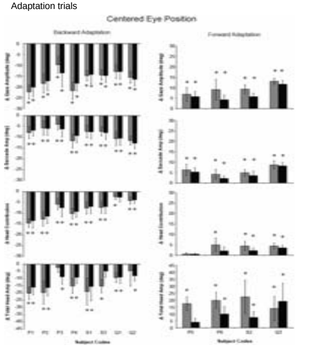


Figure 4. Summary of the change in gaze (A, E), saccade (B, F), head contribution (C, G), and total head amplitude for gaze shifts initiated from the centered eye position from 12 sessions (8 backward & 4 forward). The difference (±SD) between the pre-adaptation probe mean and the post-adaptation mean (gray bars) or post-probe mean (black bars). (*) denotes a change in movement amplitude between pre- and post means (t-test, $p<0.05$).

Citations

Freedman EG, Sparks DL (1997) Eye-head coordination during head-unrestrained gaze shifts in rhesus monkeys. J Neurophysiol 77:2328-2348

Hopp, JJ, Fuchs, AF (2004). The characteristics and neuronal substrate of saccadic eye movement plasticity. *Prog Neurobiol.* 72(1):27-53.

Judge SJ, Richmond BJ, Chu FC (1980) Implantation of magnetic search coils for measurement of eye position: an improved method. Vision Res 20:535-538

McLaughlin, S. (1967). Parametric adjustment in saccadic eye movements. *Percept. Psychophys.* **2**, pp. 359–362.

Eyes and Head Not- Aligned

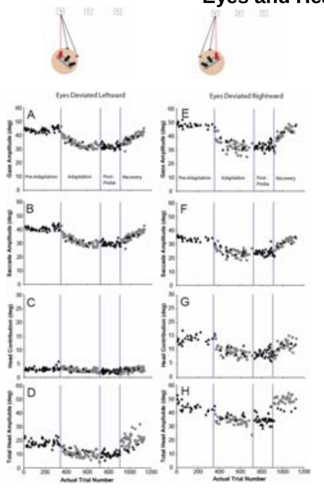


Figure 5. Gaze, saccade, head contribution and total head amplitudes of the primary gaze shifts made during pre-adaptation, adaptation, post-probe, and recovery segments of backward adaptation experiment Q1. Individual examples A-C are indicated with labeled arrows. A-D: Data from gaze shifts in which the eyes were deviated leftward (head deviated away from T1) in the orbits (mean IEP= 14.9±2.0°). E-H: Data from gaze shifts in which the eyes were deviated rightward (head deviated away from T1) in the orbits (mean IEP= 12.5±1.0°). Black triangles = adapt probe trials; Gray squares = Adaptation trials.

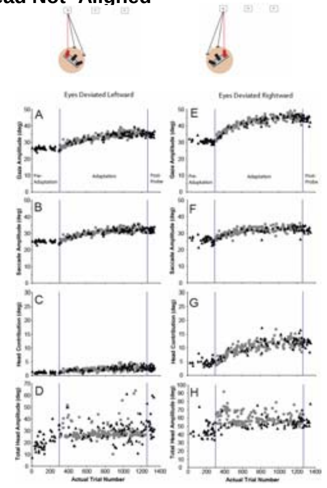
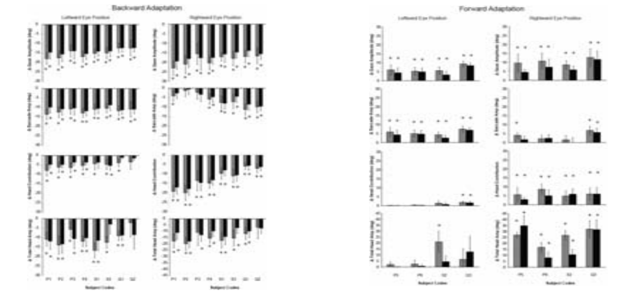


Figure 7. Gaze, saccade, head contribution and total head amplitudes of the primary gaze shifts made during pre-adaptation, adaptation, post-probe, and recovery segments of backward adaptation experiment Q1. Individual examples A-C are indicated with labeled arrows. A-D: Data from gaze shifts in which the eyes were deviated leftward (head deviated away from T1) in the orbits (mean IEP= 12.9±1.4°). E-H: Data from gaze shifts in which the eyes were deviated rightward (head deviated away from T1) in the orbits (mean IEP= 14.7±1.0°). Black triangles = adapt probe trials; Gray squares = Adaptation trials.



Figures 6 & 8. Summary of the change in gaze (A, E), saccade (B, F), head contribution (C, G), and total head amplitude for gaze shifts initiated with the eyes and head not aligned. Data were extracted from same 12 sessions shown in figure 4. The difference (±SD) between the pre-adaptation probe mean and the post-adaptation mean (gray bars) or post-probe mean (black bars). (*) denotes a change in movement amplitude between pre- and post means (t-test, $p<0.05$).

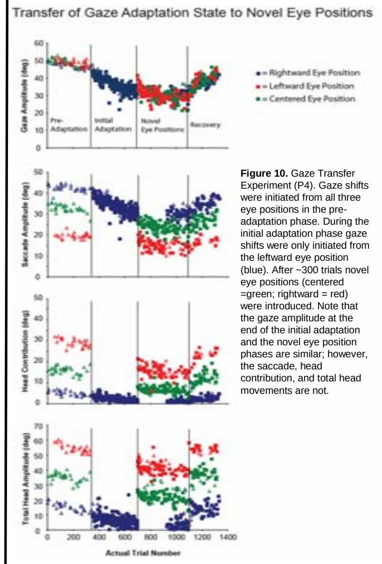


Figure 10. Gaze Transfer Experiment (P4). Gaze shifts were initiated from all three eye positions in the pre-adaptation phase. During the initial adaptation phase gaze shifts were only initiated from the leftward eye position (blue). After ~300 trials novel eye positions (centered =green; rightward = red) were introduced. Note that the gaze amplitude at the end of the initial adaptation and the novel eye position phases are similar; however, the saccade, head contribution, and total head movements are not.

Summary and Conclusions

•The "McLaughlin Task" can be used to produce large changes (>10°) in the amplitude of gaze shifts made by head-unrestrained monkey subjects (Gaze Adaptation).

•Changes in gaze amplitude tended to be smaller during forward adaptation that backward adaptation during both adaptation and probe trials.

•During both adaptation and probe trials changes in the amplitudes of primary gaze shifts resulted from changes in saccade and head contribution in an initial eye dependent fashion.

•Gaze amplitude changes induced from one initial eye position transfers to novel eye positions (Figure 10).

•We hypothesize that the changes in gaze shift amplitude, induced by surreptitious displacement of the visual target, occur at the level of a gaze shift command and not at the level of separate eye and head movement commands.

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