Smooth Pursuit

Pursuit is a voluntary response, controlled by attention to moving objects. It is characterized by smooth, conjugate eye movements.

Four Functions of Smooth Pursuit.

1) **Foveating a moving image** to maximize it's visibility.

Ex: Reading a road sign while driving

2) **Cancellation of VOR** during head tracking. Pursuit can cancel VOR for a head movement of up to 200 deg per second, compared to 70 degrees per second maximum pursuit with head still.

EX: Following a bird fly across a clear sky with head movement.

3) **Cancellation of OKN**: When tracking a small moving object across a large, stationary background, OKN tends to stop the eye. Pursuit velocity is reduced and more catch-up saccades are required.

Ex: Tracking a bird against a background of trees.

When fixating an object with a moving background, OKN tends to produce drifts which pursuit cancels.

Ex: Fixating the moon with clouds moving across it.

4) **Correction of drift imbalance in fixation**

Ex: Vestibular imbalance can cause drift away from target, pursuit corrects for slow drifts.

Measurement of Smooth Pursuit

Because the movements are relatively slow, just about any system except EOG will do.

Usually measured with a single spot moving in a relatively blank field, with the head fixed. Spots usually move in <u>sinusoidal</u> pattern or in <u>ramp</u> (constant velocity) pattern.

Dynamics of Smooth Pursuit

Latency of pursuit is 100 to 125 msec, much longer than VOR (~15 msec), but still shorter than latency to initiate a saccade (~200 msec).

Catch-up saccades will often accompany pursuits in order to correct for tracking errors.

Velocity range of pursuits is from the very slowest drifts (e.g. 1 degree in ten seconds) up to a maximum of about <u>70 degrees per second</u>. Athletes may show pursuits as high as 130 degrees per second. In practice, people rarely move their eyes that fast. For fast tracking they move their heads, for very fast tracking they make saccades.

Ex: Auto in fast lane at 60 mph moves across your field at about 200 degrees per second when viewed from shoulder of freeway.

Ex: Baseball at 70 mph moves across the field at about 1000 degrees per second when it's near the plate, much too fast to "Keep your eye on the ball."

Two Phases of Pursuit

1) In **Open Loop Phase** the pursuit response is guided by target motion which occured before the eye movement began, in the latency period.

a) Initial acceleration (first 20-40 msec) is very stereotyped and doesn't depend on initial target velocity.

b) following this, there is a variable acceleration component in which pursuit acceleration depends on the target motion seen before the eye movement began (i.e. still open loop).

2) In **Closed Loop Phase** the pursuit response is being modified by feedback from target motion on the retina. The closed loop phase begins roughly one latency period after target onset.

Predictive character of pursuits

If target motion is unpredictable, then pursuit response will show a lag of about one latency period behind the target. Ex: tracking a flying insect.

If target motion is predictable, then pursuit will track with almost no lag at all and the object will be perfectly centered on fovea. Ex: tracking a child on a swing or tracking your own hand movements.

Stimulus for Smooth Pursuit

Velocity of target

Step-ramp paradigm puts position and velocity in conflict and shows that response follows velocity. Velocity is the primary stimulus for pursuit.

Position of target

If a ramp target makes a step in the same direction as pursuit, there is a position error but no velocity error. Still if the error is small the eye increases pursuit velocity to catch up. If the error is large, a saccade may correct it.

If an afterimage is generated on the retina just outside the fovea, attempts to fixate it can engage pursuit. This produces a constant position error.

Information about eye movement

If the eye tracks a moving target perfectly, there is no more position or velocity error but the eye continues to track. Pursuit control takes into account both the retinal image motion and the eye and head motion, so we perceive a target as moving whether or not we track it. The perceived motion acts as the stimulus to pursuit.

Inferred motion

This also applies when we perceive motion of a target that isn't really visible, but is implied by other motions. Stroboscopic motion like on neon signs is an example where we infer motion of a single object from a series of flashes. Another example is the motion of a large mostly invisible object inferred from the motions of its visible parts. Ex: Tracking the hub of a bicycle wheel at night.

Proprioception

We can track the motion of our hands in total darkness, based on proprioceptive information from muscle and joint receptors.

Sound localization

In total darkness we can track the position of a moving sound with smooth pursuit eye movements.

Note that what most of these have in common is that they all involve Perceived Motion of an object. The control of pursuit involves high level integration of many cues to motion.

Pathway for Smooth Pursuit

Pathway is not known for sure, but based on a studies of animal and human stroke victims we have a "Putative pathway" for pursuit control.

The pathway is very similar to the one described for the cortical control of OKN, except that it involves several more cortical areas and one more brainstem area.

Visual information for pursuit follows the Geniculo-Striate pathway.

From Striate Cortex (aka Area 17, **V1**) signals are sent on to the Posterior Parietal (**PP**) Middle Temporal (**MT**) and Medial Superior Temporal (**MST**) areas. Neurons in these areas are specialized for motion, with large receptive fields and strong direction selectivity. Some are active in particular during smooth pursuits. Neurons in **MST** are sensitive to both target motion and eye motion, so they seem to encode the real motion of targets relative to the head. These areas have projections directly to the brainstem, and also to other cortical areas.

Lesions in MST and MT cause **Akinetopsia** (motion blindness) in one hemifield. Saccades to fixed points are still accurate, but pursuit to targets moving in the affected area are abolished.

Frontal Eye Fields **FEF** are motor areas in frontal cortex which have neurons which fire during smooth pursuit toward the same side of the head. (Right hemisphere cells fire for rightward pursuit.)

In the brainstem, the DorsoLateral Pontine Nuclei (**DLPN**) receive inputs from the cortex for pursuit, controlling pursuits toward the ipsilateral side. The DLPN projects contralaterally to the flocculus and vermis of the Cerebellum.

From the Cerebellum, the pathway follows the same as for OKN and for VOR, projecting ipsilaterally to the Vestibular Nucleus, which then projects contralaterally to the Abducens Nucleus.

Vertical Pursuit responses follow the same pathway as for horizontal, except they involve the Lateral Terminal Nucleus (**LTN**) and the Y-Group Nuclei and Dentate nuclei instead of the DLPN. Vertical eye movements are studied less and so we tend to know less about their characteristics and their pathway. Vertical pursuits tend to have lower gain at high frequencies compared to horizontal

Information Flow: Smooth Pursuit requires a steadily increasing innervation to an agonist muscle, but the stimulus is velocity of a target, so a signal transformation has to occur.

Through the course of the pursuit pathway, information begins as retinocentric target velocity signals (V1, MT),

then is converted to craniocentric target velocity signals (MST) by inclusion of eye movement signals,

then is converted to desired gaze velocity signals (FEF, DLPN, LTN) through motor control centers and

finally it is converted to changing eye-in-head position signals (Cerebellum, VN) through combination with vestibular head velocity signals and by neural integration of the desired eye velocity signals.

Disorders and conditions affecting smooth pursuit:

some produce overall reduced pursuit gain which leads to saccadic or **Cogwheel Pursuits**; others produce field-specific pursuit initiation deficits. It is very rare to have a condition which makes pursuit gain too high, although this can happen through adaptation.

Age: Older patients in general tend to have a more limited ability to follow targets with smooth pursuits. Their latencies are longer, their peak velocities are lower, their tracking gains are lower, they have more catch-up saccades. This may be due to a combination of sensory and motor deficits.

Drugs: Some drugs, such as Alcohol and barbituates will reduce pursuit gain through a depressive effect on the nervous system. Others may

interfere with focused attention and thereby impair pursuit.

Disease: A number of diseases affect pursuit, including Parkinson's, Alzheimer's, Schizophrenia. This results from a combination of motor effects and attentional effects. Virtually all major central nervous system disorders have some effect on pursuit.

Lesions in V1 produce blindness in visual field contralateral to lesion. Pursuit targets presented here are invisible to patient. If the entire visual cortex in one hemisphere is destroyed, vision near the fovea may be intact (macular sparing), allowing the patient to track targets over the full range of eye movement.

Lesions in Middle Temporal Cortex (MT) produce Akinetopsia in the contralateral visual field, so that saccades to fixed targets may be accurate but pursuit responses to moving targets presented in the affected field will be absent or deficient. Ipsilateral field may also be affected to a small degree due to overlap of representation for these areas. These cortical areas are quite small and it is rare to have a focal lesion that affects only MT, but such patients have been reported.

Lesions in Medial Superior Temporal Cortex (MST) produce visual effects similar to MT, but also produce a unidirectional pursuit deficit for targets in both visual hemifields moving toward the side of the lesion.

Lesions in Posterior Paretial Cortex (PP) produce attentional deficits, which make pursuit of small targets more difficult than larger fields. Some patients show particular difficulty when the targets are moving toward contralateral hemispace.

Lesions in the Frontal Eye Fields (FEF) produce a deficit for horizontal pursuit toward the side of the lesion.

Lesions of the DorsoLateral Pontine Nucleus (DLPN) produce a deficit for horizontal pursuit toward the side of the lesion.

Lesions of the Cerebellum can abolish pursuit if they are extensive. More focal lesions in either the flocculus or vermis will reduce pursuit gain if the other is intact.

Lesions involving the rest of the pursuit pathway will also have effects on other subsystems, such as VOR.