William James, in his monumental *Principles of Psychology* (1890), remarked:

“Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction, and Zerstreutheit in German.”
premotor cortex – a more indirect role in motor control

1. activity, as in primary motor cortex, may directly reflect present action
2. activity accompanies actions as well as planning for actions
3. action-related activity may depend on ordering of actions in a sequence
3. activity may reflect perceived actions as opposed to actual movements (as in ‘mirroring’)

[Diagrams and graphs depicting neural activity and movement routes]
firing properties related to more abstract features of a motor task I: dorsolateral prefrontal cortex neurons mark the beginning and ending of a behavioral episode

Fujii and Graybiel, Science, 2003
firing properties related to more abstract features of a motor task II: dorsolateral prefrontal cortex neurons track time intervals

TASK: monkey gets cues of different colors which indicate time interval to wait before releasing a key

 PREFRONTAL NEURONS: individual neurons respond for different cued time intervals – some build responses leading to key release time (below), some decrement responses following cue onset (above)
firing properties related to more abstract features of a motor task III: dorsolateral prefrontal cortex neurons ‘count’

**TASK:** monkey gets sample image with 1-5 dots of varying size – delay – test images are given – one has the same number of dots, the other a different number (arrangement and size of dots varies) – monkey must select the one matching the sample image

**PREFRONTAL NEURONS:** exhibit delay activity specific to particular dot ‘counts’ irrespective of their size or arrangement

Nieder et al., Science, 2002
firing properties related to more abstract features of a motor task IV: dorsolateral prefrontal cortex neurons map action sequence categories

**TASK**: monkey observes a four-item sequence wherein three buttons (push, pull, turn) are lit in different combinations – monkey must remember the sequence and then perform it

**PREFRONTAL NEURONS**: have delay activity that corresponds to one of three ‘categories’ of action sequence (AABB, ABAB, AAAA)
the pattern of efferent projections from prefrontal cortex suggests three different pathways by which prefrontal cortex can enact ‘top-down’ influences on other regions of cerebral cortex (e.g., in some forms of attention)

1. direct projections
2. projections to neuromodulatory systems
3. projections to thalamus
an example: prefrontal ‘top-down’ influences on parietal cortex during an oculomotor delayed response task – inactivation of prefrontal cortex via cooling depresses ‘working memory’ responses of parietal cortex neurons and increases errors

error rate (percent saccades to wrong site) for each of 8 directions used increases when prefrontal cortex is inactivated

parietal neuron has delay-period activity specific to the N and NW targets

delay-period activity for the same neuron is depressed when prefrontal cortex is inactivated

Chafee and Goldman-Rakic, JNP, 2000
attention as a ‘selection’ process by which responses to stimuli are enhanced or suppressed – responses of neurons in IT cortex (part of the visual ‘what’ pathway) to their preferred stimuli are strongly modulated by attention.

task: single visual cue (the target) is given followed by a delay – then two stimuli (one the target cue) are shown and the monkey saccades to the target cue –

premise: IT neurons have activity specific to particular objects during the cue phase – is their object-specific activity subject to the effects of attention?

when the pair of stimuli are presented, initially the neuron responds strongly, but this response is only transient if the preferred stimulus is not the target cue (dotted line) – the normal response of the neuron to the object has been suppressed relative to neurons whose preferred stimulus IS the target.
the timing of attention – a role for prefrontal mapping of time intervals?

Task: monkey is instructed to pay attention 1 of 4 regions of the visual field – when orientation of stimulus in that region changes, the monkey releases a bar

timing aspect: the probability that the orientation will change varies across time

Activity of single neurons in visual cortex (area V4) responding to a visual stimulus fire more if their response field (RF) overlaps the region of the visual field that must be attended (‘attend in’ vs. ‘attend out’)

Subtracting the ‘attend out’ from the ‘attend in’ firing rate curve yields the ‘attention index’, which measures the difference in response to the stimulus due to attention

The ‘attention index’ changes in accord with the probability that the stimulus will change orientation – that is, attention has a temporal component