Cost Functions and the Control of Human Arm Movement

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For a human subject asked to place the finger tip at particular targets on a horizontal plane passing through the shoulder, the arm represents a redundant manipulator. The shoulder, elbow and hand provide three degrees of freedom but the task only requires two: the subject is free to choose among many combinations of angles at the three joints. When possible, subjects tend to adopt combinations which avoid extreme positions of any one joint. This behavior has been successfully modeled by assigning U-shaped cost functions to each joint and choosing the arm configuration for which the total cost over all three joints is minimized.

Do these hypothetical cost functions represent a physiological parameter? In the pointing task the subjects are simply asked to assume a comfortable arm position. When a "comfort" function is measured separately for each joint using standard psychophysical methods, the dependence of comfort on angle is found to be U-shaped and to be virtually independent of the current angle of the other joints. These "psychophysical cost functions" show good agreement with cost functions determined by fitting the pointing data.

Muscle activation, which changes with joint angle, might be one physiological component of a cost function. This factor can be altered with a spring opposing joint movement in one direction. Under these conditions, the preferred arm configuration for a given target changes in favor of angles where the spring exerts less force--as if the cost function has been changed. In contrast, extending the hand with a pointer, which changes the geometry and the allowable arm configurations for a given target, does not affect the underlying cost functions.

When the fingers are allowed to move independently of the hand, then the arm has two extra degrees of freedom. In this case, the broad minima of the cost functions determined for each joint do not lead to a single minimum for a given target but to a band of acceptable, low-cost arm configurations, both in the model and in experiments.

This description of arm control using cost functions has been extended to the dynamics of pointing movements. When combined with elements of mass-spring control and a requirement that movements be distributed over all the joints, the model provides good simulations of simple pointing movements, including those leading to curved trajectories in experiments. This model currently is being used to investigate pointing movements in which the hand must avoid obstructions in the direct path from starting point to target.