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The nature of the cost functions for the control of the human arm movement

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The aim of the investigation is to understand the mechanisms which control the movement of the human arm. The arm is here considered as a redundant system: the shoulder, elbow and wrist joints, which provide three degrees of freedom, combine to move the hand in a horizontal plane, i.e. a two dimensional space. Thus the system has one extra degree of freedom.

Earlier investigations of the static situation led to the hypothesis that independent cost functions were attached to each of the three joints and that the configuration chosen for a given target position is that which provides the minimum total cost (Cruse, Biol. Cybern. 54, 125-132, 1986). The aim of the current investigation was to look for measurable values corresponding to the hypothetical cost functions. The first question investigated was whether the choice of the arm position depends solely on the values of the joint angles or also on the length of the limbs. Experiments using pointers of different lengths attached to the hand showed that the angles are independent of the limb length although the geometry of the whole arm was changed dramatically.

Concerning the nature of the cost functions two assumptions are possible: (a) the cost functions might represent the physiological costs necessary to maintain a given joint angle or (b) they might be completely independent of any kind of physiological costs and merely represent a "computational" value used by the neural system to solve the redundancy problem. According to the first assumption different joint angles should be used in pointing to a given target position when the elbow joint is loaded by an additional force the value of which depends on the joint angle. According to the second assumption no differences should occur. The results show that the angle values in the loaded situation deviate in the direction proposed by assumption (a). Thus the hypothetical cost functions seem not only to depend on the joint angles but also on the force which is developed by the muscles.

Psychophysical methods allow the direct measurement of a kind of cost function: the subjects are asked to give a subjective measure for the comfort of a given joint angle. The results show U-shaped curves which can be approximated by parabolas. In general, the two branches of the parabola have different slope values. The position of minimum cost (maximum comfort) for one joint showed no or very weak dependency on the angles of the other joints. For each subject these "psychophysical" cost functions are compared with the hypothetical cost functions. The latter were obtained in targeting experiments as described earlier. They are defined as those functions providing the best fit to the data according to the criterion of the smallest mean square deviation; they were calculated by means of an automatic method (using simulated annealing). The comparison showed reasonable agreement.

Thus the cost functions which can directly be measured by psychophysical experiments seem to be quite similar to the hypothetical cost functions postulated to explain the control of the movement of the human arm. Furthermore the latter seem to depend on the actual physiological costs necessary to hold a given joint position.