How does the brain coordinate movement?

Suppose you are sitting in a chair and decide to stand up and walk across the room to switch on the light. How does the brain work out what muscles to contract, by how much and in what sequence?

The human body has hundreds of joints that can be moved voluntarily so there are very many ways joint movements can be combined to achieve any particular goal. But, while those hundreds of joints can be moved voluntarily one at a time, only a very small number can be moved simultaneously independently of each other.

It is possible, nevertheless, to move many joints simultaneously if the joint movements are coordinated. For example, consider movements of the hips, knees and ankles when riding a bicycle, or movements of the scapula, shoulder, elbow, forearm and wrist when reaching to pick up a glass. Our brains learn to couple joint movements together and to control them as if they were a single movement. We call these *movement synergies*.

Acquiring a new motor skill involves learning novel movement synergies. Starting with the spontaneous movements of the foetus and neonate and continuing throughout life the brain learns through trial and error, imitation and coaching a large repertoire of movement synergies that it stores in memory. To perform a particular behaviour like standing up from a chair or rolling over in bed the brain must retrieve from memory and execute the appropriate sequence of learned synergies. Attempting to perform a synergy not learned previously leads to inaccurate, slow and stiff movements. Patting the head and rubbing the tummy is often used as an example but there are many other combinations of joint movements that are not usually learned. Damage to the brain around the time of birth can disrupt the ability to learn even the everyday movement synergies, as in cerebral palsy, while damage later in life can impair use of synergies previously instated, as in stroke.

While acquisition of movement synergies allows the brain to control many joints simultaneously, a problem still exists. Many different synergies can achieve the same movement goal(s). How does the brain select a particular one? One possibility is that it learns movement synergies that minimize demand by muscles for metabolic energy. For any particular goal there then exists a unique synergy able to achieve the goal with minimum effort. This makes sense from an evolutionary viewpoint given that both predator and prey are advantaged by moving as quickly and for as long as possible with limited available energy.

How the brain might learn minimum energy movement synergies is a computationally difficult problem. It requires knowledge of the relationships between muscle tensions and body movements and these relationships change depending on body posture, orientation of the body in the gravitational field, and on mechanical interactions between the body and objects in the environment. It has been argued that these relationships are so equivocal that they cannot be computed. From a computational neuroscience viewpoint this is a frustrating proposal because clearly the brain solves the problem every time it produces a goal-oriented purposive movement.

In this paper we use concepts from the mathematical theory of geometry and calculus on curved surfaces (i.e., Riemannian geometry) to show computationally how the brain might realistically achieve this complex task. The resulting hypothesis is offered for furthering our understanding of how the brain controls movement in both normal individuals and in those suffering neurological disorders.

Publication

A Riemannian geometry theory of human movement: The geodesic synergy hypothesis.
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