Central Generator Produces Transitions Between Two Equilibrium States During Rhythmic Arm Movements

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Introduction

Rhythmic arm movements are often considered as being pendulum-like. They may be produced by a central pattern generator (CPG) that oscillates about one equilibrium position, i.e. the position at which the movement can naturally end if the cause of oscillations (i.e., insufficient damping) is eliminated. Alternatively, a CPG may produce rhythmic transitions between several equilibrium positions of the arm thus defining not only the orientation but the spatial boundaries of rhythmic movements. We tested these hypotheses by perturbation methods.

Methods

Standing subjects (n=9) swung one or both arms synchronously or reciprocally from the shoulder joints at ~ 0.8 Hz. In randomly selected cycles, one arm (dominant or non-dominant) was transiently (for 100-350 ms) arrested by an electromagnetic device during the forward and the backward phase of swinging. Kinematic data from the endpoint markers on the hands and electromyographic activity of anterior and posterior deltoid muscles were recorded.

Results

Results showed that both unilateral and bilateral synchronized or reciprocal arm oscillations were interrupted by perturbation of one arm but that oscillations quickly resumed with a random shift in the phase. During bi-manual movements, the non-perturbed arm often stopped moving sometime after the release of the other arm but regular oscillations were resumed in both arms simultaneously. Oscillations usually resumed when both arms arrived at similar forward or backward extreme positions if a synchronous bilateral pattern was produced or at the opposite positions if the pattern was reciprocal. At these positions, EMG activity of muscles of both arms was minimal during regular oscillations and at the time when they resumed after the perturbation.

Conclusion

Results suggest that the CPG produces transitions between two equilibrium arm positions without destabilizing either of them. In this framework, the frequency and spatial boundaries of arm oscillations may be controlled by changing the rate of the transitions and by adjusting the equilibrium positions, respectively. These positions appear to be natural points at which the system may modify its behavior: to halt the oscillations, resume them at a new phase (as observed in the present study), or initiate a new motor action. Our findings are relevant to locomotion and suggest that walking may also be generated by transitions between several equilibrium states of the body.