

The influence of external dynamics on motor planning

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Optimal control strategies have been implemented to overcome the ill-posed nature of motor planning by minimizing cost functions to identify potential motor planning criteria. Different theories posit that humans aim to optimize kinematic, dynamic or variance costs in the planning of supported reaching movements in the horizontal plane. While each theory explains some facet of movement trajectories in the horizontal plane, none can fully explain real human behavior. A more complete exploration of human motor behaviors across a variety of tasks is needed to understand the degree to which each of these theories explains normal human behavior. Here, we discuss the influence of inertial, viscous and gravitational dynamics on motor planning. We conclude that changes in external movement dynamics can highlight key differences between the performances of leading motor planning strategies.

We simulated the human arm interacting with either a mass in the hand or a viscous force field. We found that the mass did not change the trajectories predicted by the minimum torque change (MTC) or minimum end point variance (MEPV) hypotheses. In contrast, viscous forces clearly differentiated MTC and MEPV predictions from both minimum jerk (MJ) predictions and from human behavior. We conclude that learned behavior in the viscous environment could arise from minimizing kinematic costs, but could not arise from a minimization of either torque change or end point variance.

We also considered the role of naturally occurring dynamics on human behavior and optimal control strategies. Human subjects performed 10 cm, center-out movements in a vertical plane intersecting the shoulder and produced hand paths that were slightly curved. The change in direction-dependent gravity torques was significantly ($p_{\text{slope}}=0.0008$) correlated ($r^2=0.868$) with curvature; an increase in gravity torques throughout the movement resulted in counterclockwise curvatures, and a decrease in gravity torques resulted in clockwise curvatures. We then simulated a two degree of freedom dynamic arm model. We found that MTC replicated human hand paths in five out of eight movement directions. In the other directions, MTC predicted the direction, but underestimated the magnitude of human path curvature. MEPV hand paths drastically overestimated the curvature seen in subjects. Our results indicate that even a simple, steady state, dynamic environment, like gravity, can cause systematic, behavioral differences over its horizontal analog.

We show that movements made interacting with an inertial load, a viscous force field or a gravitational force elucidate key differences in motor planning strategies. Our results indicate that changes in external dynamics influences the predictions of current models of optimal control. People did not consistently favor a particular cost in their movement selection: external viscous forces elicited straight hand paths that violated dynamic optimality, and gravitational forces elicited curved paths that correlated with direction-specific torques and violated kinematic optimality. We therefore reject the notion that a single optimality principle can explain normal human behavior; rather people consider a variety of movement features and plan movements dependent on task specific context and dynamics. A much richer set of psychophysical and computational studies are necessary to determine what quantitatively constitutes normal motor control.

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