An inverse optimization approach to understand human acquisition of kinematic coordination in bimanual fine manipulation tasks

Kunpeng Yao and Aude Billard
Learning Algorithms and Systems Laboratory (LASA)
École polytechnique fédérale de Lausanne (EPFL)

Tasks that require the cooperation of both hands and arms are common in human everyday life. Coordination helps to synchronize in space and temporally motion of the upper limbs. In fine bimanual tasks, coordination enables also to achieve higher degrees of precision that could be obtained from a single hand. We study the acquisition of bimanual fine manipulation task in watchmaking. Watchmaking requires assembly of pieces at millimeter scale. It demands years of training. We contrast motion kinematics performed by novice apprentices to those of professionals.

Fifteen subjects, ten novices and five experts, participated in the study. We recorded force applied on the watch face and kinematics of finger and arms. Results indicate that expert subjects wisely place their fingers on the tools to achieve higher dexterity. Compared to novices, experts also tend to align task-demanded force application with the optimal force transmission direction of the dominant arm.

To understand the cognitive processes underpinning the different coordination patterns across experts and novice subjects, we follow the optimal control theoretical framework and hypothesize that the difference in task performances is caused by changes in the central nervous system's optimal criteria. We formulate kinematic metrics to evaluate the coordination patterns and exploit inverse optimization approach to infer the optimal criteria. We interpret the human acquisition of novel coordination patterns as an alteration in the composition structure of the central nervous system's optimal criteria accompanied by the learning process.