

Principal components as motor synergies of human catching movements

Till Bockemuhl, Nikolaus F. Troje and Volker Durr

A central question in motor control is how the CNS deals with redundant degrees of freedom inherent in musculoskeletal systems. The human arm is a prime example for such a system. It shows a vast variety of behavior and plays a key role in most aspects of our life. However, because of its biomechanical complexity, the arm poses a formidable control problem to our CNS. In this study we analyzed movements performed by human subjects, which were asked to catch a ball launched towards them on 16 different trajectories. Subjects had to initiate movements from 2 different starting positions. Motor activity of the right arm was recorded using optical motion capture and was transformed into 10 joint angle time courses by a model-based optimization algorithm. The resulting time series of arm postures were analyzed by principal components analysis (PCA). We generally found that more than 90% of movement variance was captured mostly by as few as 2 principal components (PCs). Furthermore, subspaces spanned by PC sets associated with different catching positions varied smoothly across the arm's workspace. When we pooled complete sets of movements, 3 PCs were still sufficient to explain 80% of the data's variance. This indicates strong kinematic couplings between the joints of the arm. We hypothesize that flexible and context-dependent behavior like multijoint human arm movement does not necessarily require complex neural algorithms. Instead, we show that catching movements towards diverse targets can be generated efficiently by linear combinations of a small set of cardinal movement synergies.