Changes in rates of contributions of muscular and non-muscular torques to net torque in complicated skill acquisition

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Introduction
Of many studies on motor learning, few studies focused on change in either movement patterns or kinetics in a learning process. Since movements of segments result from not only muscular torque but also non-muscular torque (ex. gravity and/or inertia). Using these torques efficiently may make a learner successful in the acquisition of skills. A couple of previous studies reported that the subjects used muscular torque to counterbalance motion dependent torque, parts of the non-muscular torque, throughout their practice sessions (Schneider K. et al. 1989, Heise G.D. & Cornwell A. 1997). They also found that the rates of contributions of the each torque component to the net torque remained throughout practice. The tasks in their studies were, however, simple planar movements. It is doubtful to apply the results to complicated 3-D movements. The purpose of this study is, therefore, to examine whether the rate of contributions of each torque component to the net torque change or not throughout practice, when the task is a 3-D multi-segmental arm movement.

Methods
Seven male volunteers were required to practice a novel 3-D arm movement task. The task was composed of cyclic movements of forearm supination/pronation, shoulder abduction/adduction, horizontal abduction/adduction, and external/internal rotation. They practiced the movement until they satisfied a statistical criteria based on a kinematic comparison with an expert model. The mean duration of practice was 9.5 (SD = 3.5) weeks. The subjects were digitally recorded using four 120 Hz infrared cameras. Three-dimensional coordinates of 7 markers attached on the body were calculated using DLT method. The upper limb was modeled as three linked segments. Newton Euler's inverse dynamics was used to calculate to kinetics for the upper limb. Four torque components were calculated; net torque (NET), motion-dependent torque (MOT), muscle dependent torque (MUS), and gravitational torque. To reveal

![Figure 1](image-url): Exemplar forearm segment MUS, MOT and NET torque profiles for movements performed early and late in practice. With learning, contributions of the torque components pattern changed. Early in learning, MUS and MOT counterbalanced each other (black arrows). But later in learning, compensational pattern increased (gray arrows).
change of the torque pattern, we carried out cross-correlation analyses with zero time lag between MOT and MUS profiles for each axis for each segment. The angle between MOT and MUS were calculated for detail investigation of these parameters.

**Results & Discussion**

With practice, the average speed of each segment increased significantly, due to enlarging the range of motion. For each segment, the NET torque profiles changed clearly with practice. For the results of cross correlation analysis, the coefficients were close to -1 at most axes in early stage of practice. This means that MOT and MUS profile showed the counterbalance pattern (left panel in Fig. 1). In contrast, the coefficients approached 0 at medial lateral axis of upper arm and anterior posterior axis of forearm in the late stage of practice. From the qualitative observation, the reduced coefficients resulted from the increased complementary pattern and the decreased counterbalance pattern of MOT and MUS profile (right panel in Fig. 1). During the complementary pattern, both of MOT and MUS acted to the same direction of NET. It showed clearly changes in the rates of contributions of torque components to NET with practice. It may suggest the changes in motor control strategy of learner for movement production with skill acquisition. In previous studies, kinematic degree of freedom of the tasks was limited in a planar movement. The changes of movement patterns and kinetics with practice in the previous studies, therefore, could be observed less than that in the current studies in which the 3-D arm movements was used. The constraints imposed on the tasks in the previous studies may limit and/or mask change of their movement patterns and kinetics.

Though the complementary pattern at some axes increased in the late stage of practice, the angle formed by MOT and MUS decreased with practice (Fig. 2). This means that both torques were acting to more opposite directions of each other in the late stage of practice. To counterbalance the increased MOT associated with the increased movement velocity, subjects had to enlarge the MUS and act in the opposite direction of MOT. The subjects could learn the capability to act MUS in the opposite direction to MOT as well as the capability to enlarge MUS generation with practice. Development of counterbalance between MOT and MUS could assist to keep a dynamic equilibrium at the joints during movements.

The results of the present study showed that clearly change of movement patterns and kinetics of 3-D multi-joint movements with practice. Especially, the changes in the rates of contributions of MOT and MUS to NET could showed improvements of strategy motor control of subjects during skill acquisition.

**Reference**


![Figure 2](image_url)  
*Figure 2*: Exemplar angle profiles between MOT and MUS of forearm segment with practice for two subjects. The angle decreased with practice.