INTRODUCTION

Previous studies on finger force interactions during finger flexion force production have used inter-finger matrix (enslaving matrix) to determine the finger dependency (Zatsiorsky et al. 2000). The inter-digit matrix has been considered as a constant source of positive covariations between finger forces during pressing in uncontrolled manifold hypothesis (Scholz et al. 2004). However, our knowledge is limited in terms of the inter-digit matrix during finger force production in extension and a task involving both flexion and extension.

The aim of this study was to (1) investigate effects of finger force direction (flexion and extension) on finger enslaving, (2) differences in enslaving between tasks of unidirectional force production and continuous changes of finger force directions, and (3) validity of proximity hypothesis (fingers closer to a task finger produce larger involuntary forces).

METHODS

Apparatus: Two-directional (tension and compression) force sensors for four fingers (Index, middle, ring, little) with amplifiers (Models 208 M182 and 484B, Piezotronics, Inc.) were used. The frame was attached to an aluminum panel with a vertical slit (14.0 cm). C-shaped aluminum thimbles were attached on the bottom of each sensor. The frame was tilted at 25° with respect to the antero-posterior axis such that all finger joints were slightly flexed when the distal phalanges were positioned inside the thimbles. The forearm and hand was fixed in a brace.

Procedure: Each subject (n=18) performed two tasks: individual finger maximum force production (MVF task) and oscillatory flexion-extension force production (oscillation task).

The MVF task was composed of 8 conditions: 4 conditions for task fingers (I, M, R, and L for single-finger tasks) in 2 finger force directions (flexion and extension). During each trial, all fingers were in the thimbles, and subjects were asked to produce maximum isometric force with a task finger in flexion or extension over a 3-s interval. The subjects were instructed to concentrate on the task finger and not to pay attention to non-task fingers.

The oscillation task was composed 4 task finger conditions. For each finger oscillation task, subjects performed 20 flexion-extension cycles for each finger tasks for 20 seconds (1 Hz). The target forces (20% of MVC’s in flexion and extension) and the force produced by the task finger were
shown on a computer screen. This was used for visual feedback of finger forces. A metronome was also used to control the frequency of finger force oscillations. The four conditions were performed at 120 beats per minute. The forces produced in either direction were 20% of the task finger’s MVC. The conditions lasted 20 seconds (for a total of 20 cycles). A cycle is a flexion force production continued with an extension force production.

For MVF tasks, regression analysis was performed between the task finger force and non-task finger force. The data ranged from 0 to 20% of the task finger MVF were used for the regression analysis. The slopes of the regression lines were used to determine the ratios of non-task finger force to task finger forces. For oscillation tasks, the data were separated into flexion part and extension part. We used frequency response function to calculate the gains. Task finger force was used as an input signal and non-task finger force was used as output signals. The slope ratios and gains were used as the measures of finger inter-dependency (so-called enslaving) for MVF and oscillation tasks, respectively.

RESULTS

In MVF task, finger enslaving in flexion was smaller than that of extension. In oscillation task, however, difference between finger enslaving effects of flexion and extension was minimal. In MVF task, neighboring fingers showed larger enslaving effects during middle and ring fingers tasks than during and little fingers tasks. In oscillation task, neighboring fingers showed larger enslaving effects during ring and little finger tasks than during index and middle fingers tasks. Enslaving effects are significantly larger in task of MVF (unidirectional force production) than in task of oscillation.

CONCLUSIONS

The larger enslaving of fingers closer to task fingers found in our study support the proximity hypothesis. The difference of enslaving effects in MVF and oscillation tasks shows that force production pattern has effect on finger enslaving. These observations also show that finger force direction has influence on enslaving effects in unidirectional force production but has no influence on enslaving effects in force production of continuous changes of finger force directions. We conclude that inter-digit matrix is dependent on force production patterns.

REFERENCES