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ACQUISITION OF INDIVIDUATED FINGER MOVEMENTS THROUGH MUSICAL PRACTICE

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Abstract—Individuated finger movements represent a key feature of hand dexterity. However, our understanding of mechanisms underlying the acquisition of this motor skill is limited. The present study aimed to identify the effects of daily motor training on acquisition of individuated finger movements. Ten musically naïve individuals performed piano practice for 4 successive days, and hand kinematics were evaluated using a motion capture system. The results showed a decrease in movement covariation across fingers with practice, particularly at the ring and little fingers. The decrease was more pronounced in the pair of fingers with lower independent control prior to the practice. Furthermore, a few finger pairs demonstrated facilitated movement independence when the subject was provided with visual feedback (VFB) regarding the rhythmic accuracy of motor actions following each practice. The results provide evidence for the enhancement of individuated finger movements through dexterous hand use during piano practice, which suggests plastic adaptation of the neuromuscular system associated with independent control of finger movement. **© 2014 IBRO. Published by Elsevier Ltd. All rights reserved.**

Key words: motor learning, neuroplasticity, fine motor control, motor skill, hand dexterity.

INTRODUCTION

The neuromuscular architecture of the hand constrains the independent control of individual finger movements. The constraint includes the anatomical linkages between the tendons and muscles of the hand (Leijnse et al., 1993; Lang and Schieber, 2004a), the synchronous firing of motor neurons innervating into adjacent finger muscles (Kilbreath and Gandevia, 1994; Keen and Fuglevand, 2004; Winges et al., 2008), and the shared representation of individual fingers in the motor cortex (Schieber and Hibbard, 1993; Sanes et al., 1995). Consequently, the motion of a single finger yields a covariation of motion at the adjacent fingers (Häger-Ross and Schieber, 2000). This movement covariation may simplify the control of relatively simple hand movements such as grasping (Santello et al., 1998, 2002;Mason et al., 2001; Gentner and Classen, 2006) and haptic exploration (Thakur et al., 2008) by reducing the dimensionality of the control of multiple joints/muscles in the hand (Overduin et al., 2012; Santello et al., 2013). However, dexterous hand use, which represents skilled motor behavior, requires moving multiple fingers in an opposite direction, or even independently, against these neuromuscular constraints. This motor skill is sometimes impaired through development of overtraining-induced neurological disorders such as focal dystonia (Curra et al., 2004; Sohn and Hallett, 2004; Rosenkranz et al., 2009; Furuya and Altenmüller, 2013), which implicates its association with neuroplasticity. Of particular importance is an understanding of the neuroplastic mechanisms subserving the individuated finger movements, which may not only shed light on acquisition and loss of hand dexterity, but also aid in designing an optimal program for facilitating fine motor control for unskilled and elderly individuals (Shim et al., 2004) and for patients with movement disorders that exacerbate dexterous hand use (Lang and Schieber, 2004a; Raghavan et al., 2006; Brandauer et al., 2012; Park et al., 2012).

Previous studies that compared repetitive finger movements between musicians and non-musicians using a cross-sectional design demonstrated enhancement of individuated finger movements in musicians (Parlitz et al., 1998; Slobounov et al., 2002; Aoki et al., 2005). A recent study also demonstrated the equal independence of movements across fingers in expert pianists (Furuya et al., 2011a) over a wide range of movement rates (Furuya and Soechting, 2012), which differed from the findings in musically untrained individuals (Häger-Ross and Schieber, 2000; Zatsiorsky et al., 2000; van Duinen and Gandevia, 2011). These findings suggest the acquisition of this motor skill through extensive training, presumably through plastic neuromuscular adaptations (Jäncke, 2009). However, several confounding factors remain, such as the genetic predisposition of neuromuscular anatomy and function and the explicit instruction provided through music education. A longitudinal study would serve for

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Abbreviations: DIP, distal-interphalangeal; IKI, inter-keystroke interval; MCP, metacarpophalangeal; NFB, normal feedback; PIP, proximal-interphalangeal; ROM, range of motion; VFB, visual feedback.

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better understanding whether the superior independent control of finger movements in musicians is a product of nature or nurture (Wan and Schlaug, 2010).

Piano performance provides a rich and natural environment that requires independent finger control such as a precisely timed strike and release of keys in succession with multiple fingers (Furuya et al., 2011a). The spontaneous covariation of movements across fingers may elicit unwanted tones and/or distorted rhythm and articulation. Thus, a mastery of piano playing should accompany skill acquisition for moving fingers independently. In addition to extensive piano practice, specific instruction in piano can play a role in the acquisition of independent control of finger movements. For example, during motor training of the independent control of static force production in fingers, visual feedback (VFB) regarding the motor performance facilitated independent finger control (Chiang et al., 2004). This result suggests the importance of providing extrinsic information on movement accuracy for acquiring this skill. Since perceptual abilities that are also not well fine-tuned in untrained individuals as compared to musicians (Kraus and Chandrasekaran, 2010) may make it difficult to gain precise information on movement error, extrinsic VFB may aid in facilitating feedback error learning (Kawato, 1999). Indeed, motor skill acquisition with explicit VFB activates distinct neural networks (Debaere et al., 2003; Ronsse et al., 2011).

The primary goal of the study was to identify the effects of daily musical training on individuated finger movements. Based on the previous findings of lower independent movement control in the middle and ring fingers compared with the index and little fingers for the untrained non-musicians (Häger-Ross and Schieber, 2000; Zatsiorsky et al., 2000) but not for the expert pianists (Furuya et al., 2011a), we hypothesized a larger learning gain at the fingers with potentially low independent control. It was also postulated that joints with a larger range of motion (ROM) would display a greater learning effect. We also assessed the effect of practicing with provision of VFB regarding the rhythmic accuracy of motor actions on individuated finger movements. We hypothesized improvements in independent finger control following musical training and its facilitation through providing explicit VFB.

EXPERIMENTAL PROCEDURES

Participants

Ten musically naïve adult individuals were randomly assigned to two groups. One group (one female, four males; age: 21–24 yrs) was provided explicit VFB regarding the rhythmic accuracy of movements (i.e., VFB) following each practice trial (VFB group). The age-matched control group (five males; age: 21–24 yrs) did not receive any explicit VFB regarding performance (normal feedback (NFB), group). All participants were right-handed, with a laterality index of 89.1 ± 8.1 (all > 80) (Oldfield, 1971). All participants had neither formal education in playing musical instruments prior to the experiment nor other expertise requiring dexterous use of the hand (e.g. sewing, painting). The experimental protocol was approved by the local ethics board of Kwansei Gakuin University, and all participants provided informed consent prior to the experiment. The experiment was performed according to the Declaration of Helsinki.

Experimental design

The experiment consisted of 50 practice trials for 4 successive days (200 trials in total). During the practice, each participant played a certain tone sequence consisting of 12 strokes with a predetermined fingering that used all possible finger pairs of the left hand (Fig. 1A). In each trial, the four fingers were used three times. The index, middle, ring, and little finger always struck a key of F, E, D, and C, respectively. The thumb was not included because our previous study demonstrated different movement patterns between the thumb and the fingers (Furuya et al., 2011a). We chose the non-dominant left hand because this hand is less frequently used in daily and sports activities compared with the dominant hand. The participant played a digital piano (YAMAHA, P-250) with an inter-keystroke interval (IKI) of 500 ms in synchronization with a metronome (two strokes per second) at a predetermined speed with which each key was depressed (90-MIDI velocity; note that MIDI velocities provided by the interface range from 1 to 127). This task was repeated 50 times per day, among which the first five and last five trials were used to record and assess the hand kinematics (Fig. 1B). During the

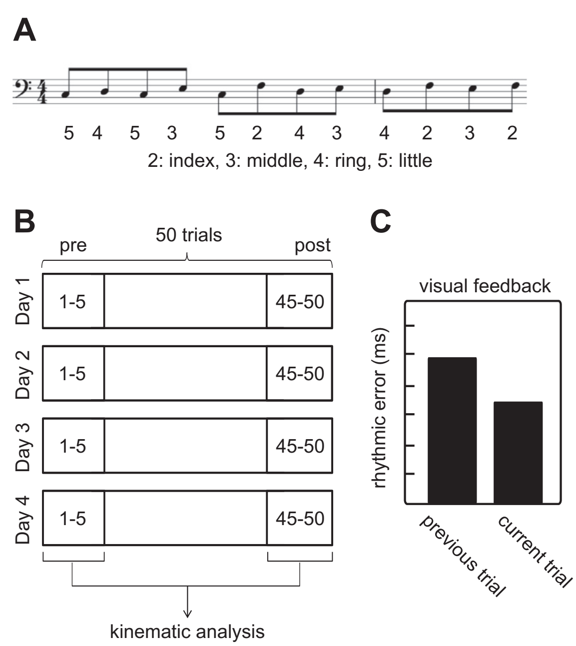

Fig. 1. (A) The practice task on musical score. The number below each note specifies the fingering (2, 3, 4, and 5 correspond to the index, middle, ring, and little fingers, respectively). (B) The experimental flow. Each day of training consisted of 50 practice trials. The initial and final five trials were used for analysis, defined as the pre-training and post-training sessions, respectively. (C) Visual feedback on rhythmic accuracy of keystrokes during one previous (left bar) and current (right bar) trials. The plot was visually presented on a PC monitor located in front of a participant after each trial only for the VFB group.

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