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DISTINCT DIGIT KINEMATICS BY PROFESSIONAL AND AMATEUR PIANISTS

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Abstract—Many everyday tasks such as typing, grasping, and object manipulation require coordination of dynamic movement across multiple joints and digits. Playing a musical instrument is also one such task where the precise movement of multiple digits is transformed into specific sounds defined by the instrument. Through extensive practice musicians are able to produce precisely controlled movements to interact with the instrument and produce specific sequences of sounds. The present study aimed to determine what aspects of these dynamic movement patterns differ between pianists who have achieved professional status compared to amateur pianists that have also trained extensively. Common patterns of movement for each digit strike were observed for both professional and amateur pianists that were sequence specific, i.e. influenced by the digit performing the preceding strike. However, group differences were found in multi-digit movement patterns for sequences involving the ring or little finger. In some sequences, amateur subjects tended to work against the innate connectivity between digits while professionals allowed slight movement at non-striking digits (covariation) which was a more economical strategy. In other sequences professionals used more individuated finger movements for performance. Thus the present study provided evidence in favor of enhancement of both movement covariation and individuation across fingers in more skilled musicians, depending on fingering and movement sequence.

Key words: covariation, dynamic movement, fine motor control, independent finger movement, multi-digit coordination, long-term training.

INTRODUCTION

A wide variety of tasks require controlling dynamic movement of individual digits as in playing a musical instrument where the precision of pressing, striking or plucking by one or more digits determines the quality of the performance (Palmer et al., 2009; Keller et al., 2010; Furuya et al., 2011a,b; Goebl and Palmer, 2013; Albrecht et al., 2014). Dynamic patterns of covariation among joints within and across digits are observed during these movements in addition to other tasks such as typing, American Sign Language, and in grasping and manipulating objects (e.g. Soechting and Flanders, 1997; Santello and Soechting, 1998; Jerde et al., 2003; Weiss and Flanders, 2004). Patterns of coarticulation have also been observed where elements within a sequence are influenced by the preceding and subsequent elements (Engel et al., 1997; Jerde et al., 2003; Winges et al., 2013). The task itself influences the expected patterns of covariation and coarticulation. For example, the temporal constraints imposed by playing the piano often result in specific patterns of covariation across multiple-muscles and joints of the same limb, especially when larger movements are required to perform the next strike, such as a thumb-under maneuver (Engel et al., 1997; Furuya et al., 2011a). Without a specific rhythmic temporal constraint, movements similar to playing the piano such as typing tend to be executed in a more serial fashion where differences in spacing between strikes do not negatively impact task performance and may reflect biomechanical constraints (Soechting and Flanders, 1992).

While the task itself may impose certain expected patterns of covariation, the actual patterns of movement can also be influenced by the ability to produce individuated finger movements. With training, changes in the performance of movement may reflect expertise. For example, in highly skilled pianists, very distinct patterns of inter-joint and multi-digit coordination were observed (Furuya et al., 2011a,b) and were maintained across different tempi (Furuya and Soechting, 2012). Comparative studies between the professional and amateur pianists have also demonstrated that professionals tend to have smaller amounts of spillover of force exerted by one finger to the adjacent fingers (Parlitz et al., 1998; Slobounov et al., 2002; Aoki et al., 2005). For example, repetitive piano keypresses with one finger while keeping the remaining digits immobilized yielded smaller magnitude and shorter duration of force exerted by the immobilized fingers in the professional pianists (Parlitz et al.,

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Abbreviations: ABD, abduction; ANOVA, analysis of variance; IKI, inter-keypress interval; IP, interphalangeal; LOOCV, leave-one-out cross validation; MCP, metacarpophalangeal; PC, principal component; PIP, proximal interphalangeal joints; ROT, angle of thumb rotation; SVM, support vector machine.

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1998). In addition, hand kinematics of professional pianists was characterized by an equal amount of movement spillover across fingers (Furuya et al., 2011a), which differed from less individuated movements at the middle and ring fingers than the other digits in musically untrained individuals (Hager-Ross and Schieber, 2000). Thus individuals with extensive piano training had superior independent control of finger movements against innate neural spillover and biomechanical linkages across digits (Zatsiorsky et al., 2000; Lang and Schieber, 2004; Schieber and Santello, 2004; van Duinen et al., 2009; Yu et al., 2010).

By contrast, neurophysiological studies using transcranial magnetic stimulation (TMS) provided evidence that professional pianists tend to have reduced suppression of motor neurons innervating muscles connected with the fingers adjacent to a moving finger (i.e. surround inhibition; Shin et al., 2012). Rosenkranz et al. (2005) also found reduced short intracortical inhibition in muscles controlling fingers adjacent to the finger controlled by the vibrated muscle in musicians, which could support lower surround inhibition among digit muscles due to muscle spindle inputs. These findings indicate a greater readiness for producing coupled motion across fingers (multi-digit covariation) in the skilled players. The reduced surround inhibition is likely to result from repetitive training of the coupled motion between the fingers (Kang et al., 2013). Thus an alternative possibility is that for individuals who underwent extensive piano training, less pronounced individuated finger movements would be observed during performance.

The purpose of the present study was to characterize patterns of hand movements during musical performance by the professional and amateur pianists. Although increased independent control of the digits appears to be one of the hallmarks of advanced training for dexterous movements, the influence of training on patterns of covariation among multiple digits is not known. Therefore, of particular interest were group differences in the amount of movement covariation, which could provide evidence for the two alternative influences of extensive musical training, i.e., does multi-digit control become more individuated or synergistic? Our general hypothesis was that highly trained pianists who had achieved ''professional'' status would exhibit patterns of multi-digit coordination reflecting an advanced level of control, such as economy of movement, compared to the amateur pianists.

EXPERIMENTAL PROCEDURES

Ten healthy pianists (nine right handed, four male, 33 ± 10 yrs.) with no known neurological disorders or significant hand injuries participated in the study. Five of the subjects were professional pianists who had won prizes at international and/or national piano competitions, while the other subjects were amateur pianists with a range of training experiences (Table 1). The experimental protocol was approved by the University of Minnesota's Institutional Review Board and all subjects gave informed consent prior to the experiment.

Subjects played with the right hand, 14 different excerpts ranging from 9 to 24 sixteenth notes from 11 musical pieces which were: ''Das Wohltemperierte Klavier, Vol. 1 No. 15 and Vol. 2 No. 1, 2, 10, 15'' by Johann Sebastian Bach, ''Étude Op. 10 No. 1, 4, 8 and Op. 25 No. 11, 12'' by Frédéric Chopin, and ''15 Études Op. 72 No. 6'' by Moritz Moszkowski. The excerpts were selected for their use of the right hand and a large number of fingering sequences without consecutive use of the same digit or of chords. Digit number was specified so that all subjects played with the same fingering. Subjects were instructed by demonstration to play at a loudness of 100 MIDI velocity in synchrony with a metronome which provided the tempo (inter-keystroke interval = 125 ms). Subjects were also instructed to play with legato touch (a key was not released until the subsequent key was depressed) and were allowed to practice to familiarize themselves with the piano and the musical excerpts so each excerpt could be played accurately and consistently across ten trials. Trials with mistakes were discarded (about 5–10% for professionals and 20–25% for amateurs). Discarding trials with mistakes limited our examination to accurate keystrikes which for amateur subjects may have resulted in playing at a slower than prescribed tempo.

Subjects played on a digital piano (Roland ep-5, 61 keys), connected to a Windows computer (SONY VAIO VGN-Z90PS) via a MIDI interface (Roland EDIROL UA-4FX). The score and fingering was presented on a computer monitor in front of the piano. Posture of the right hand was defined by 15 joint angles measured by a right-handed glove with open fingertips with an angular resolution of the glove was $<0.5°$ (Cyberglove, Virtual Technologies, Palo Alto, CA, USA). The recorded joint angles from each of the four fingers were the metacarpophalangeal (MCP) and proximal interphalangeal joints (PIP) as well as abduction (ABD) angles between the fingers. At the thumb, MCP, ABD and interphalangeal (IP) joint angles were measured as well as the angle of thumb rotation (ROT) about an axis passing through the trapezio-metacarpal joint of the thumb and index MCP joint. The glove was calibrated for each participant using a standard set of postures. Joint angle data were recorded at a temporal resolution of 12 ms (~83 Hz) for 1 s. A custom LabView script (National Instruments) was used to record joint rotations from the glove and MIDI data from the keyboard (1-ms resolution). Joint rotation data were differentiated to yield a set of joint angular velocities for each trial. The data were segmented into three-keypress sequences centered on each of the five target digits. For the central keypress by the thumb, index, middle, ring, and little fingers, respectively, we analyzed n = 25, 34, 29, 23, and 17 three-keypress sequences yielded from the 10 excerpts for each subject. Relative joint movements were examined by segmenting the data ±100 ms around the target digit strike. Peak joint velocity was defined as the maximum velocity in either the extension (positive) or flexion (negative) direction as determined by the sign of the average joint velocity ±10 ms around the central strike.