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Finger motion in piano performance: Touch and tempo

Werner Goebl[1] and Caroline Palmer[2]

[1] Department of Computational Perception, Johannes Kepler University Linz, Austria
[2] Department of Psychology, McGill University, Canada

This study investigated movement properties of pianists' fingers with three-dimensional motion capture technology while pianists performed melodic passages at a range of tempi. The main question was whether finger motion dynamics change with performance tempo, an important issue for practicing and training. Kinematic landmarks determined from the finger trajectories changed considerably as the tempo became faster; piano touch was under deliberate control only at slow tempi. Individual differences in performance speed led to specific claims about desirable finger dynamics for successful piano playing.

Keywords: motion capture; piano performance; finger dynamics; proportionality; touch

Piano pedagogues disagree on how performers should develop the ability to perform scale passages evenly and dexterously at very fast rates. One side points out the importance of practicing fast sequences at very slow tempi, while others hold that practicing at the intended fast tempo is more appropriate. The main argument of the latter is that movement strategies change considerably across different tempi—for example, as human gait changes from walking to running—and movements that are learned while practicing slowly are not useful at fast tempi. We address here whether kinematic properties of finger movements scale proportionately with performance tempo.

We investigated the movements of pianists' fingers and hands as they performed melodies at a wide range of tempi to test the proportionality hypothesis. Furthermore, we examined how pianists' touch—the way pianists' fingers approach the piano keys—is affected by tempo by measuring keystrokes containing a finger-key landmark, a marker for a pianist's touch. This

work aims to generate potential recommendations for piano pedagogy, based on observations of skilled pianists performing at different tempi.

METHOD

Participants

Twelve highly-trained pianists participated in the study. They were 20 to 33 years old (mean=27.0 years; NB. one participant was 61 years old with 40 years of experience in playing the piano) and had 10-25 years of piano lessons (mean=18.7 years); most were piano performance students in Montreal.

Stimuli and design

One isochronous melody (the "fast" melody) was created that was easy to perform with the right hand and could be continuously repeated (see notation in Figure 2); it was designed to be performed at very fast tempi (tempo conditions were 7, 8.4, 9.6, 10.7, 11, 7, 12.3, 14 and 16 tones/s, presented on different trials); the pianists decided at what tempo they stopped performing (open-ended design). The tempo was indicated by a metronome in a synchronization-continuation paradigm. For comparison, we include data from two "moderate" melodies that contained 16 tones and were performed at moderate to medium fast tempi (2, 4, 6, and 7 tones/s), as reported earlier (Goebl and Palmer 2008).

Procedure

A passive motion capture system (Vicon 460) equipped with six infrared cameras tracked the movements of 4 mm reflective markers glued on pianists' finger joints, hand, and wrist at a sampling rate of 250 frames/s. The motion trajectories of the five finger-tip markers were smoothed with functional data analysis techniques (Ramsay and Silverman 2005) and analyzed in the vertical dimension (height above piano key surface).

Kinematic landmarks were extracted prior to each keystroke (see also Figure 2): the key-bottom landmark (KB, the finger is stopped by the keybed) and the maximum finger height (mxH, to be interpreted as the beginning of the finger movement) for all keystrokes. An additional finger-key landmark sometimes occurs when fingers strike the keys from a distance above the key surface (struck touch, see Askenfelt and Jansson 1990) and the acceleration peak is larger than a threshold of 10 m/s^2 (for details, see Goebl and Palmer 2009). A pressed touch does not feature such a landmark. In addition, we determined the peak velocity at which the finger arrives at the key surface.

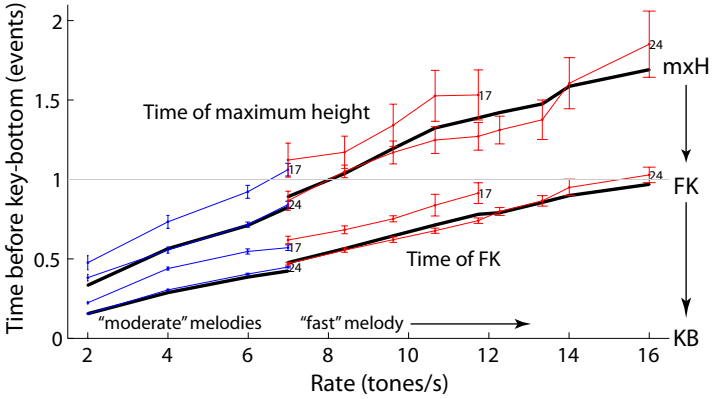

Figure 1. Time of maximum height (mxH, upper graphs) and time of finger-key contact (FK, lower graphs) in number of events prior to note onset (key-bottom, KB) by performed tempo. Thick line is the mean of 12 pianists; Pianists 17 and 24 are plotted separately.

RESULTS

The open-ended design of the "fast" melody generated the following results: all pianists were able to perform up to a rate of 11.7 tones/s (sixteenth notes at 176 bpm, beat=quarter note); 8 played up to 12.3, 7 up to 13.3, 6 up to 14.0, and only 3 up to 16.0 tones per second (considerably faster, for example, than the metronome markings of Chopin's Op.25/11). The "fast" pianists had similar amounts of piano lessons and years of playing, compared to the "slower" pianists; the only difference was the weekly practice, significantly higher for the "fast" players (25 vs. 13 hours). The following analyses attempt to identify kinematic properties that distinguish the fast players from the slow players.

Figure 1 shows the average timing values of the identified landmarks by tempo condition for the moderate melodies (2-7 tones/s) and the fast melody (7 tones/s and faster). Timing has been normalized on an event-to-event basis relative to KB contacts to allow comparisons across tempo conditions. At about 8 tones/s, the movement initiation (time of maximum height) toward the current keystroke occurs more than one keystroke before (starts to overlap with) the previous keystroke (KB). Furthermore, the time of FK contact approaches the time of the previous keystroke at the fastest rates. This overlap in movement landmarks between current and previous keystrokes may be

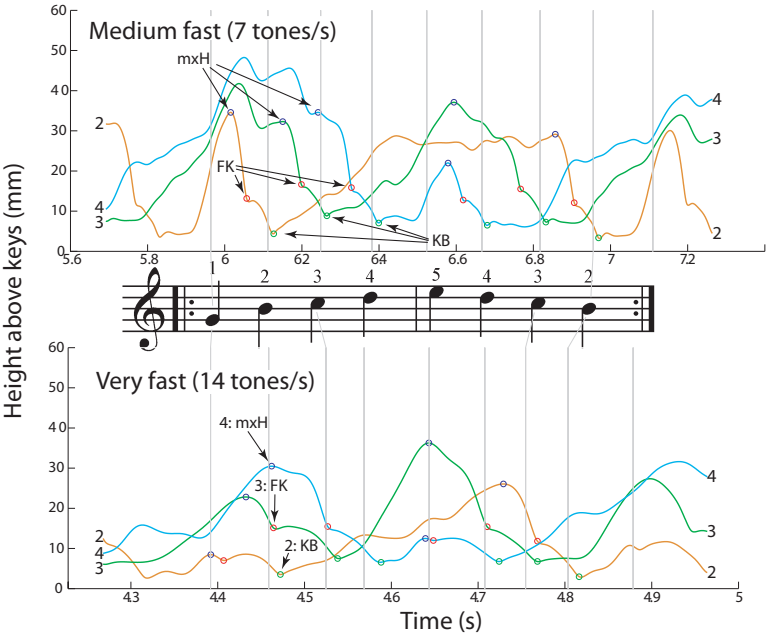

Figure 2. Finger trajectories of index (2), middle (3), and ring finger (4) of Pianist 24 playing one cycle of the "fast" melody at a medium fast tempo (upper panel) and a very fast tempo (lower panel). Three kinematic landmarks are labeled in the finger trajectories before each keystroke: the maximum height (mxH), the finger-key contact (FK), and the key-bottom contact (KB). Vertical lines denote MIDI onset times.

a speed-limiting feature in piano performance. This is shown further in Figure 2 for one pianist's trajectories of index, middle, and ring fingers. In the medium-fast condition (7 tones/s, top panel), the index finger's keystroke was finished striking the second tone (B4) before the next keystroke (middle finger, C5) was initiated (mxH); at very fast rates (14 tones/s, bottom panel), the index finger had not yet reached key-bottom for the same tone while the next (middle) finger had already made key contact (FK), and the second-next (ring) finger (D5) had started its descent towards the key.

To demonstrate that landmark overlap is important for performing at fast rates, we contrasted two different pianists. Pianist 17 is a "slow" player who mastered the minimal number of tempo conditions; she played the piano over the past 15 years, but stopped a year ago; she practices 7 hours per week and performs occasionally in church. Pianist 24 was able to produce the very fast

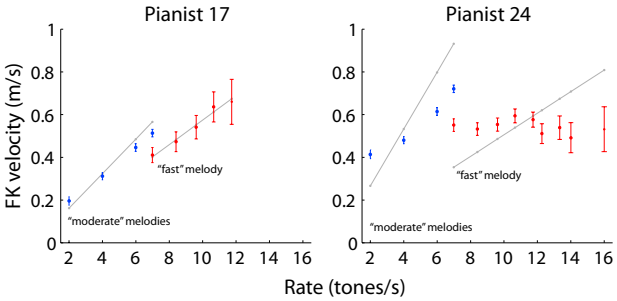

Figure 3. Finger velocity in meters per second at finger-key contact (FK) against performance rate, separately for Pianist 17 (left) and Pianist 24 (right). Proportional scaling with rate is plotted with solid lines.

tempo conditions; he played the piano for 20 years and still studies piano actively; he practices 21 hours per week and performs in public 4-5 times per year. The individual landmark timing for these two pianists is shown in Figure 1. Pianist 17 needed longer than Pianist 24 to perform a keystroke at a given tempo. Thus, her keystroke landmark timing overlaps with those of previous keystrokes at slower tempi than do Pianist 24's keystroke landmarks. Moreover at each pianist's fastest performed tempo condition, the FK timing occurred close to the arrival (KB) of the previous keystroke

Goebl and Palmer (2008) identified two groups of pianists who differed in their playing behavior across tempo conditions: a "low-FK" group who showed a positive relation between FK landmark proportion and tempo (low at slow tempo conditions) and a "high-FK" group with high (close to 1) FK proportions for all tempo conditions. These two groups differed also at the velocity with which their fingers arrived at the key surface (FK velocity): the velocities of the low-FK group scaled proportionately with the tempo conditions, but not those of the high-FK group. The fingers of the low-FK group arrived at the key surface with twice the velocity when the performance tempo doubled.

We analyzed the same FK measures for the pianists performing the "fast" melody in this study; they all showed ceiling effects in their FK proportions at all tempi faster than 7 tones/s and no proportionality overall in the FK finger velocities. The FK measures were also contrasted for the two exemplary pianists; their mean finger velocities at finger-key contact are plotted against the full range of performed tempi in Figure 3 for the moderate melodies (2-7 tones/s) and the fast melody (7 tones/s and faster). The "slow" pianist (17) showed approximate proportionality across the tempi, whereas the "fast"

pianist (24) did not. These findings suggest that the link between performed tempo and FK velocity might be detrimental to fast playing because proportionality cannot be maintained at extremely fast speeds.

DISCUSSION

Pianists' finger movement dynamics changed across different performance tempi; finger movements at key contact changed considerably as pianists accommodated faster tempi. Overall, these findings suggest that practicing at the final tempo is important from a motor control perspective. Furthermore, individual differences indicated that dissociating different finger movement properties from performance tempo may be essential for fast piano playing. However, individual cases of finger velocity-tempo proportionality implied that practicing slowly should be done very softly (that is with low FK velocity) so that finger movements at slow rates become more similar to those typically seen at final fast rates.

This research demonstrates how motion-based approaches could be established more widely in the future to enhance our understanding of the complex movement patterns executed by skilled pianists and to develop potential recommendations for piano pedagogy.

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Address for correspondence

Werner Goebl, Department of Computational Perception, Johannes Kepler University Linz, Altenberger Strasse 69, Linz 4040, Austria; *Email:* werner.goebl@jku.at

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