

Pianists, who attend to the integral relationship of their particular musculoskeletal characteristics to the piano technique at hand, discover an efficient path to technical advancement and, consequently, to injury prevention. Thus, a study of pianists' hand biomechanics in relation to different piano techniques is highly relevant, as hand features may influence various techniques in different ways. This

arm and elbow abduction/adduction; contrarily, radial deviation is excluded in this study because it can be extensively supported by the elbow and upper arm abduction.

Hand and arm weights were measured, after a brief session of weight-relaxation training, in a level position (sitting position) with the scale on a tabletop. This gave the carrying hand and arm weights that pianists use rather than the

ses were performed for quantitative comparisons among all bivariate biomechanics variables and between biomechanics and performance variables. Qualitative observation of 12 profiles provides additional insights. Table 2 shows the 12 pianists' biomechanics and performance profiles.

RESULTS

Descriptions

Biomechanics Simple description in Table 3 shows that hand lengths ranged from 15.3 to 20.6 cm, with the average length of 17.7 cm. Hand width ranged from 9 to 11.85 cm, with the mean width of 10.5 cm. Finger length ranged from 7.61 to 9.33 cm, with the average 8.56 cm. Composite finger span 10...5 ranged from 13.3 to 18.87 cm with the mean 16.21 cm. The composite finger span 3...5 ranged from 8.3 to 12.13 cm with the average 9.8 cm. Wrist ulnar deviation ranged from 27.5 to 50° with the average of 35.5°. Hand weight ranged from 1.5 to 3.5 lbs with the average weight of 2.19 lbs, and arm weight ranged from 4.5 to 8 lbs with the average weight

ter notes played in 60 s, each quarter note value, 600 ms), the real-time MIDI clock pulse comes to 6.25 ms ($600 \div 96$).*

Legato playing is calculated in direct relation to the percentage of a momentary overlap between key off and the next key onset timing. Voicings measured by calculating the percentage of the average difference of key velocities of upper and lower notes of all thirds. Synchrony was the key onset timing of each third monitored by MIDI event clock time. Range and the average time lapse between two notes are hand calculated to measure asynchrony. Dynamic range is based on the MIDI key velocity (KV) range of 1...127. The higher rate of legato, voicing, and synchrony, a greater dynamic range, and relatively faster and even tempo are the targeted performance aims.

Biomechanics and Playing Data Analyses

Simple descriptive statistics were used to show the variability among the 12 pianists. Two-tailed Pearson correlation analy-

tempo and ulnar deviation ($0.886, p=0.01$), while all other biomechanical features suggest negative association with tempo. Besides ulnar deviation, there are no other correlations between hand biomechanics and performance. Bivariate data among the music variables show no significant correlations among performance indicators.

Qualitative Observation

Arm weight Pianists 3, 6, 8, 10, and 11, with heavier arms, did not show any common pattern in their performance outcome.

Gender Male pianists generally featured larger hands with wide spans but not necessarily an enhanced ulnar wrist mobility. No other gender-specific patterns emerged.

Asynchronous gap between the two notes in the scale of thirds:

TABLE 3. Biomechanics Statistics for the 12 Pianists

Variable	No.	Mean	SD	Median	Min	Max
Hand length (cm)	12	17.73	1.34	18.05	15.3	20.60
Hand width (cm)	12	10.52	1.13	10.65	9.0	12.30
Finger length (cm)	12	8.56	0.52	8.66	7.61	9.33
Finger span 1...5 (cm)	12	16.21	1.60	15.92	13.3	18.87
Finger span 3...5 (cm)	12	9.99	1.19	10.10	8.3	12.13
Ulnar mobility (deg)	12	35.45	6.97	32.75	27.5	50.00
Hand weight (lbs)	12	2.18	0.59	2.00	1.5	3.50
Arm weight (lbs)	12	6.59	1.37	6.25	4.5	8.50

Contrarily, data suggested negative relationships between all Music). Informed by numerous anecdotal testimonies, biomechanics variables and tempo. None of the other per today's pedagogues are well aware that these exercises may formance variables, articulation, dynamic voicing, or syncause serious injury. Rather, finger individuation is devel- chrony, all important attributes to achieve musical quality, oped by whole arm...finger coordination, conditioning the was influenced by hand biomechanics. This is consistertiming of finger flexion, building strength of intrinsic mus- with Ortmann's observation that trained pianists, either with cles between fingers, enabling steady musculoskeletal fixation light and tapered fingers or with chubbier hands, both at the MCP and interphalangeal joints, strengthening extrin- accomplish the desired tones. sic muscles of the forearm, and conditioning the shoulder

This report is a part of an exploratory study which experand upper arm. In this light, Jerde's approach to neurologi- imented with a series of carefully selected technical excerptal digit...hand coordination is more appropfflate. played by 12 (13 in previous rep)skilled pianists. I began Kentner witnessed many good piano pedagogues teaching the study with some preconceptions but with no set hypothesstudents with most unlikely looking hands to play virtuosic ses. Previous empirical studiehave revealed positive rela- piano by requiring intense exercises to stretch an octave (or tionships among joint mobility, finger span, and skilled more) and widen gaps between fingerthis may be because, piano playing; but the prominent role of wrist deviation in joint mobility, finger spans, and touch control can be devel- the ulnar direction in skilled piano playing was not antici- oped by properly balancing arm and hand weight as part of pated. Further, the lack of correlations between all hand biopianists' technical development, regardless of the more rigid mechanics and wrist ulnar deviation and the nonrelationshipbone structure and other static features of the hand. of all hand biomechanics (except wrist ulnar deviation) in Artistic precision and scientific precision are conceptually disparate; playing scales in thirds with mechanical precision playing the scale in thirds were not expected. would not only be biomechanically awkward but also musi-

Leijnse and his team studied musicians' anatomical would not only be biomechanically awkward but also musi- restrictions of bidigital finger system and questioned whethercally undesirable. Hence, looking at the detailed musical certain stretch exercises can permanently improve fingeraspects is imperative in scientific study involving music per- independence. They considered finger independence primaformance. Individual biomechanics and performance priori as a function of disconnection between tendons thatfiles inform the researcher about unique connections allows larger extension. Such separation of anatomical fundbetween the body and performance outcome as controlled by tion is problematic. Some well-known pedagogues of the pastindividual pianists. Sakai and his colleaguested many taught exercises involving high individual finger lifting to variations among individual pianists and their techniques. increase finger independence (e.g., my own teacher, the pianists in this current study used coordinated finger and famous pedagogue Aube Tzerko of UCLA and Aspen Schoolweight techniques to play the scale-in-thirds exercise. It

TABLE 4. Correlation Matrix Among Biomechanics Measurements

	Hand Length	Hand Width	Finger Length	Finger Span 1...5	Finger Span 3...5	Ulnar Deviation	Hand Weight	Arm Weight
Hand length	1	0.869	0.896	0.605*	0.767	...0.210	0.528	0.799

demonstrated that skilled pianists create solutions to different piano technical problems by applying their unique set of biomechanics to achieve proficient performance. To this end, knowing one's hand biomechanics would be very useful in developing efficient skills for various techniques.

Current piano pedagogy maintains that the essential requirement of skilled piano-playing lies ultimately in the mind.

Pianist 1 is a 27-year-old female graduate piano performance major with 22 years of keyboard playing both on the piano and church organ. This pianist's hand biomechanics shows the average hand lengths, spans, weight, and mobility among the 12 pianists. Performance data indicate total playing time of 606 TMCT and playing tempo of MM = 63.37. She has good control of legato playing (94%), voicing (72.5%), and dynamics (a range is 55 to 80 KV with an average deviation of 6). Asynchrony of two notes is wide (0 to 75 ms) with an average deviation of 10.95 ms, which may be attributable to her training as an organist. In organ playing, asynchronous key attack is used to emphasize important notes to compensate for the lack of the dynamic touch control mechanism.

Pianist 2, a 21-year-old female doctoral student with 14 years of training, aspires to become a college faculty-level performer. She has larger (17.1 and 9.3 cm) and lighter hand (1.5 lbs) with slightly heavier arm (6 lbs) than the previous pianist. She also has wider finger spans (16 and 8.8) and better wrist mobility (45°). Her performance has smaller harmonic asynchrony (0...19 ms) and slightly faster tempo (MM = 67).

Pianist 3 is a male university piano professor with over 30 years of serious piano playing. He has significantly larger (18.6, 11.5, and 9.12 cm) and heavier hand and arm (3.5 and 8 lbs) with wider spans (17.17 and 11.18 cm) and large wrist mobility (50°). He played with faster tempo (MM = 69.44) and smaller asynchrony (0...13 ms). This profile demonstrates a strong association of favorable biomechanics and longer performance experience with good performance outcomes.

Pianist 4, a 37-year-old female doctoral student, has large (18.1, 10.6, 8.82 cm) and heavy hand and arm (2.75 and 6 lbs) with smaller outer 3...5 finger span (8.68 cm) and relatively small wrist ulnar deviation (39°). This playing shows slower tempo (MM = 54.79), less consistent legato (37.5%), and moderate dynamic range (43...73 KV). Despite the large hand and over 25 years of training, proportionately smaller outer finger span and small wrist ulnar deviation seem to be associated with slower tempo and lesser touch control. Tension might be related to the lack of flexibility and smaller hand span for this large-handed pianist. Conversely, we can also speculate that lack of wrist mobility and small outer hand span may be the cause of tension.

Pianist 5 is a 35-year-old female with 8 years of training. She has the average hand size (16, 9.4, and 7.76 cm) and finger spans (13.3 and 8.3 cm) with smaller ulnar deviation (32.5°). Performance data