The Use of Multimodal Feedback in Retraining Complex Technical Skills of Piano Performance

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Abstract—Piano students working to improve technique often practice the same passage over and over to achieve accuracy, increase speed, or perfect interpretive nuance. However, without proper skeletal alignment of hands, arms, and shoulders and balance between the muscles involved, such repetition may lead to difficulties with, rather than mastery of, technique and stylistic interpretation and even physical injury. A variety of technologies have been developed to monitor skeletal alignment and muscle balance that serve to help students and teachers make needed corrections during performance by providing immediate biofeedback. This paper describes and illustrates a multimodal use of these biofeedback technologies and the powerful advantages of such a multimodal approach in making the student and teacher not only aware of improper alignments and balances in real time (or for later review) but also aware of approaches to correct them and improve musical outcome. The modalities consist of hearing playback through a Disklavier piano; simultaneous visual feedback displayed as a piano roll screen of what was played; video recording synchronized with the Disklavier and piano roll feedback; motion analysis of the arms, hands, and fingers; and electromyographic recordings of the muscle actions involved. *Med Probl Perform Art* 2005;20:82–88.

Learning to perform music extends far beyond the simple concept of "playing the right notes." With the acquisition of basic skills, it takes years of intensive instructive guidance and practice to develop the more complex levels of musical expression and style. Fine motor control, as modulated by well-developed listening skills, is essential for achieving the nuances of expressive timing and dynamics one chooses as models to emulate. In overzealous efforts to achieve this, many pianists practice the same passage over and over. Such repetition may in fact lead to difficulties with technique and, in the extreme, physical injury. This often results in a disturbance of coordinated motor control, inhibiting pianists' ability to control the production of sound at the instrument. In fact, poor posture, faulty technique, unfamiliar repertoire, and excessive finger force, unnatural position of the thumb or hand, hyperextension of the joints or fingers, and repetitive overuse and practice are all considered factors contributing to piano-related injuries by those in both the medical and pedagogy fields.[1–8]

However, despite the level of awareness of these problems among researchers in the field, several studies indicate that many teachers and students are still uninformed about them and the preventative measures to be taken. Complex tasks, such as the refinement of fine motor control programs, must be intimately linked with detailed and effective aural analysis skills to achieve high-level musical performance.

The present study examines several forms of biofeedback for identifying and correcting pianists' technical problems. It is generally impossible to gain fine control of subtle motor responses lacking feedback of signals arising from these responses. However, if one can somehow amplify these signals so that they can be appreciated, then attainment of such control frequently becomes possible.[9] The forms of biofeedback discussed in this paper have been used separately as well as together to help pianists identify and correct technical problems. The following section describes each form of feedback along with a brief history of related research.

BIOFEEDBACK

Musical Instrument Digital Interface Technology and Music Sequencing

The ability to monitor, that is, gain feedback regarding one's own performance, seems to be an essential aspect in the process of musical skill acquisition.[10] Musical Instrument Digital Interface (MIDI)-equipped instruments are a powerful and widely available tool with which to gain manual control of the keyboard that also permit quantification of important aspects of performance.[11–14] These instruments provide a means of evaluating the diverse individual determinants of the total musical output/product: the sound generator, the interface between the musician and the sound generator, and the tactile and, importantly, visual reality of the instrument that provides feedback to the musician when he or she uses it.[15]

These instruments also provide information on the timing and velocity of finger movements by which the performer's understanding of the phrase structures of the music is expressed.[16,17] It is in terms of such information that, for

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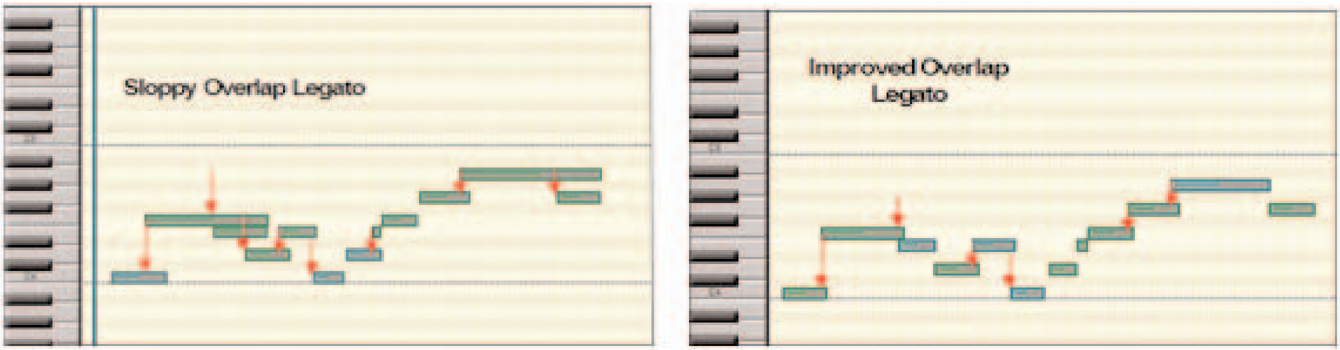

FIGURE 1. Piano roll of sloppy overlap (left) and improved overlap (right).

example, differences in interpretation of the same composition by different performers can be quantified, studied, and compared.[18,19] Palmer[20,21] generated a piano roll graphic that included a gray-scale plot of dynamics. She has used this display as the basis for studying music aesthetics. A study by Tucker et al.[22] showed that a concert-level pianist improved his performance of a trill dramatically within minutes. This was accomplished via visual feedback of modified notation that reflected the exact duration of the notes played.

In this laboratory, we have explored the capability of feedback-assisted imitation of selected phrases performed by well-known artists to enhance piano students' perceptual and technical mastery of interpretation.[23,24] MIDI data, visually displayed as a piano roll by music sequencing software, provide visual performance feedback while hearing playback through the Disklavier (donated by Yamaha Corp. of America). This form of feedback is helpful in correcting the mechanics of articulation.

Disklavier is an acoustic piano equipped with optical sensors that measure (1) the time intervals elapsing between key strikes, referred to as inter-onset intervals, (2) the velocity of each strike in determining dynamics, and (3) the duration with which each key is held down, for possible data analysis and/or playback. These parameters are recorded in Sound and Motion Picture Television Engineering (SMPTE) time code in hours, minutes, seconds, and frames at a rate of 25 frames per second. The data can be read through the music sequencing software. Inter-onset timing measurements of the notes can be deduced by subtracting the onset of each note from the onset of the previous note. The following example illustrates the usefulness of this feedback in addressing such issues as poor technique.

One student was unaware of her "lazy" fingers. Her instructor had told her repeatedly that she was overlapping her notes. Her response was, "There is always an overlap legato when playing Chopin." When she saw the piano roll and heard her playback, she exclaimed, "This is horrible! I had no idea my fingers were overlapping like this." She immediately began to correct the problem. The graphs in Figure 1 show her initial playing and the improvement made after receiving feedback in the session. There is still a slight overlap between the notes, which is necessary for the legato she intended to produce. She said, "Now I try to pay more attention to my fingers and listen more intently in my practice sessions and in my performances. I realized that most of my playing consisted of playing notes and listening very little to what I was doing."

Wanting to address the relationship of body alignment and hand and finger position to the pianist's performance and technique, the senior author incorporated digital video recording of the pianists' hands while playing as another form of visual feedback.

Digital Video Recording and Motion Analysis

Linked through a synchronization box, the MIDI-equipped piano is slaved to the video camera as the time code from the video is stripped onto the MIDI sequence. MIDI keyboard recordings and video can be played back simultaneously, providing feedback on sound, body alignment, and hand and finger position at the keyboard from perspectives that pianists themselves do not hear and see while performing, thereby revealing technical flaws of which they were otherwise unaware.

However, the playback of the video recording in real time does not help pianists identify precisely what hand and finger movement(s) may be creating or adding to technical problems. To address this factor, motion analysis software was used to analyze pianists' technique. By moving frame by frame, forward and backward, through a selected video clip, one can track minute changes in finger and hand position that might have been invisible to the eye during performance.

Almost immediately, it was apparent to the researchers that this form of feedback was not able to help pianists identify problems such as excess muscle tension that need to be addressed in retraining technical movements. The authors decided instead to incorporate feedback from surface electromyography (sEMG) measurements of muscle tension in the forearm in tandem with the video analysis.

Electromyography

sEMG is a computerized electrophysiologic technology that is an objective tool for assessment and diagnosis of mus-

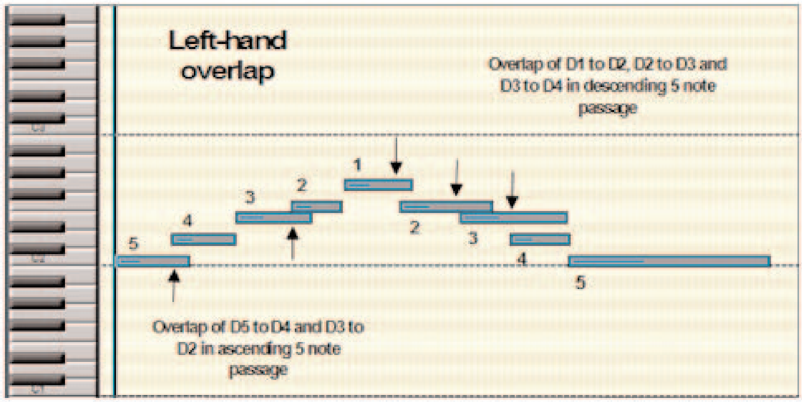

FIGURE 2. Piano roll graph of 5-finger exercise on October 20.

cular electrical activity. The use of sEMG feedback as part of a treatment package for musicians has produced positive results in overall tension reduction in the acquisition of fine motor skill,[25] for example, tension relief in pianists[26,27] and in a woodwind player.[26] The hypothesis is that sustained levels of muscle contraction inhibit smooth motor movements and contribute to fatigue in practicing and performing. Other studies indicate that the problem may be a truncated tension-relaxation cycle.[28-30] Professional pianists seem to relax immediately after depressing the key,[31] making the tension-relaxation cycle more reliable and extending their endurance.[32] Biofeedback was used to reduce left arm extensor electromyographic activation of string players during performance.[33] The musicians themselves confirmed improved performance, specifically in reduced tone and in enhanced technical ability in extending the wrist and fingers.

MULTIMODAL APPLICATIONS

In various combinations, MIDI recording and playback, piano roll score, video recording and motion analysis, and sEMG provide the performer with extensive information about the physiology of music performance and can be helpful in identifying and correcting technical problems and resolving repetitive stress injuries in pianists. The following example illustrates how these auditory and visual biofeedback modalities have been used to assist pianists.

Pianist X is a female college student with 12 years of piano lessons. She reported pain in her left wrist and weakness in the left hand. Disklavier recording, video, and sEMG were used to assess the problems. While wearing surface electrodes attached to the extensor carpi radialis and flexor carpi (see, respectively, the red and blue lines in Figures 3 and 6) in her right forearm, she was instructed to play an ascending and descending 5-finger exercise on the Disklavier at an approximate speed of mm = 100, five times with a rest period after each one. The surface electrodes were attached in order to measure muscle tension because, while a pianist's hand may look relaxed on the surface, there is often a disturbance in the necessary tension-relaxation cycles in playing. The tension is measured in terms of microvolts arising from the summation of the passage of multiple units of action potentials between two points on the muscle. The summation of the action potential passage shows up on the sEMG recordings as an amplitude form: the greater the number of passing action potentials, the higher the amplitude of the microvoltage. Motion capture software was used in tandem with the sEMG and Disklavier recording.

The MIDI file was analyzed in the music sequencing program for note overlap. The note bars in Figure 2 highlighted by arrows in the boxes are held over into the next note to be played. There is an overlap of D5 into D4 and D3 into D2 in the ascending scale and D1 to D2, D2 to D3, and D3 to D4 in the descending scale.

On the ordinate of the graphs (Figures 3 and 6) to the right are shown the units of measurement in terms of which muscle tension was measured. On the abscissa is indicated the passage of time as marked off into alternating segments of muscle activity and rests. On the graphs, line numbers 1, 3, 5, 7, and 9 mark the end of action phases; lines 2, 4, 6, and 8 mark rest phases. These lines were inserted by depressing the space bar on the computer keyboard, marking the time periods of activity and rest to the tempo of the metronome beat.

In Figure 3, the sEMG graph indicates a high level of tension in the extensor during activity (average, 78.82 μV). Although the tension level is reduced in the rest phase (average, 36.03 μV), it should be lower. In the top motion capture, D3 depresses the key in a flatter position and the last knuckle is collapsed. In the bottom capture, the bridge collapses as D1 strikes the key.

Pianist X received biofeedback in 5 weekly sessions. The note bars in Figure 4 show a marked technical improvement in Pianist X's 5-finger exercise compared with Figure 2. There is no overlap from D5 to D4 and from D3 to D2 in the ascending scale and D2, D3, and D4 in the descending scale. The note bars in Figure 2 indicate overlap between the digits mentioned previously. The graph in Figure 5 shows the difference in note overlap between sessions.

In Figure 6, the sEMG graph indicates a reduced level of tension in the extensor during activity (average, 51.73 μV).

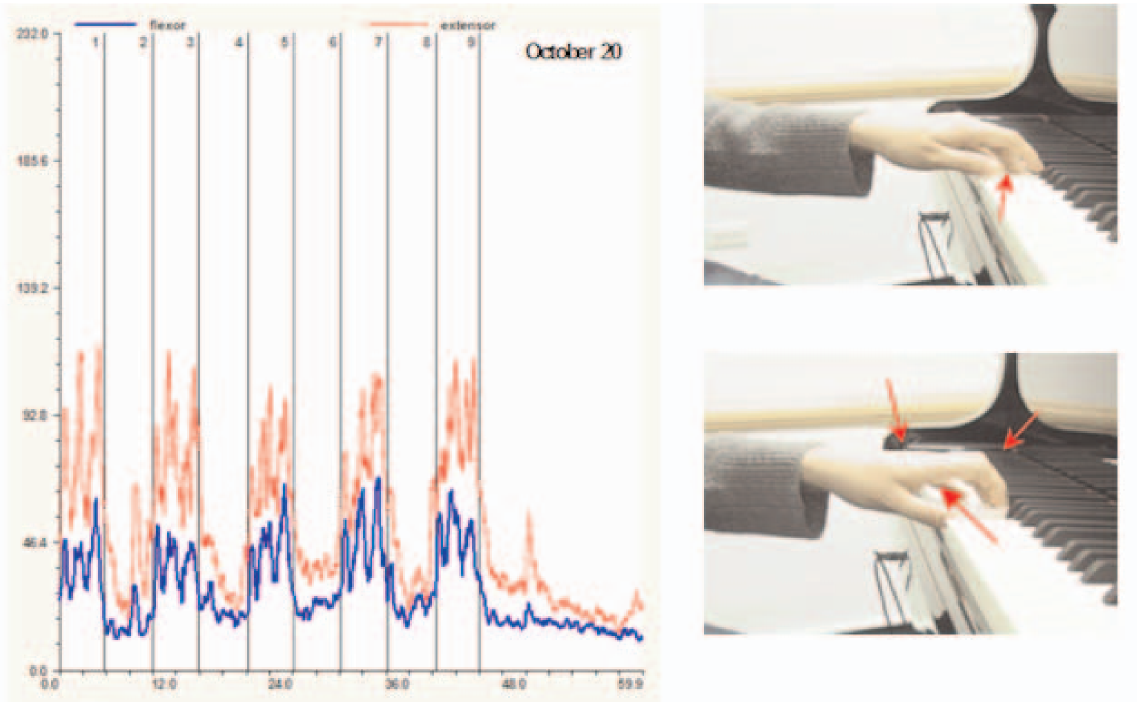

FIGURE 3. Surface electromyography graph of 5-finger exercise performed on October 20 and hand and finger position before treatment. Note that the ordinate, expressed in microvolts, is not drawn to the same scale as in Figure 6. The metric on the abscissa is in terms of seconds.

The tension level is also more reduced in the rest phase (average, 13.97 μV). As indicated by the motion capture clips, in the corrected position, D3 strikes on the fingertip without collapsing the last knuckle. The bridge in a natural curved position is much higher than before.

In comparing the 5-finger exercise readings in Figure 3 and Table 1 (in which Pianist X's hand position was closer to the keys and fingers were collapsing) with those in Figure 6 and Table 1 (in which the hand position was corrected), it is clear that in the active phase there was notably more tension in the extensors with the collapsed position (average, 78.82 μV; Table 1) than with it lowered (average, 51.73 μV; Table 1). This difference is statistically significant ($t(8) = 12.663$, $p < 0.001$, two-tailed). There was also significantly less tension in the extensors during the rest phase after (average, 13.97 μV) versus before (average, 38.03 μV) ($t(8) = 8.821$; $p < 0.001$, two-tailed).

With the preceding analysis as a general background, it is important to note in Figures 3 and 6 the patterns evident in the 5-finger exercises and the transitions at play between (1) the active and rest phases, (2) the technical improvement as evidenced in Figures 2 and 4 and (3) compared in Figure 5, and (4) the improvement in alignment of the hand and fingers as shown in Figures 3 and 6. These are indicative of how Pianist X responded to the training and feedback given by the instructor and the technology involved. Pianist X has been pleased with the results. She is under the impression that the feedback really helped.

> It takes time but I can see the results. The shape of my hand at the keyboard is changing. I feel more in control of each movement. The EMG graphs have helped me become aware of the amount of tension I was holding in my arms, hands and fingers at all times. The video of my hand from different angles than I

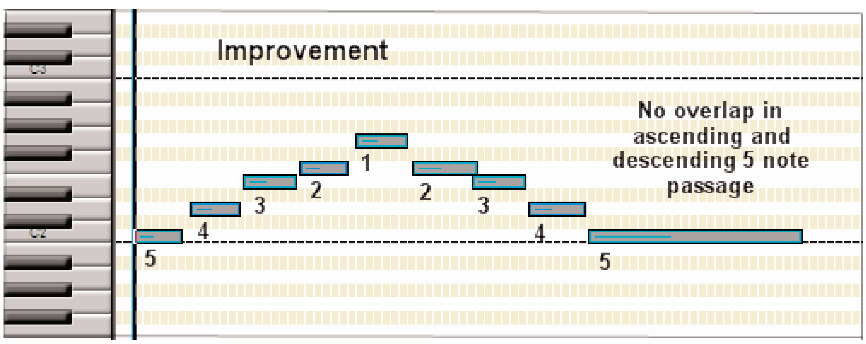

FIGURE 4. Piano roll graph of 5-finger exercise on December 1.

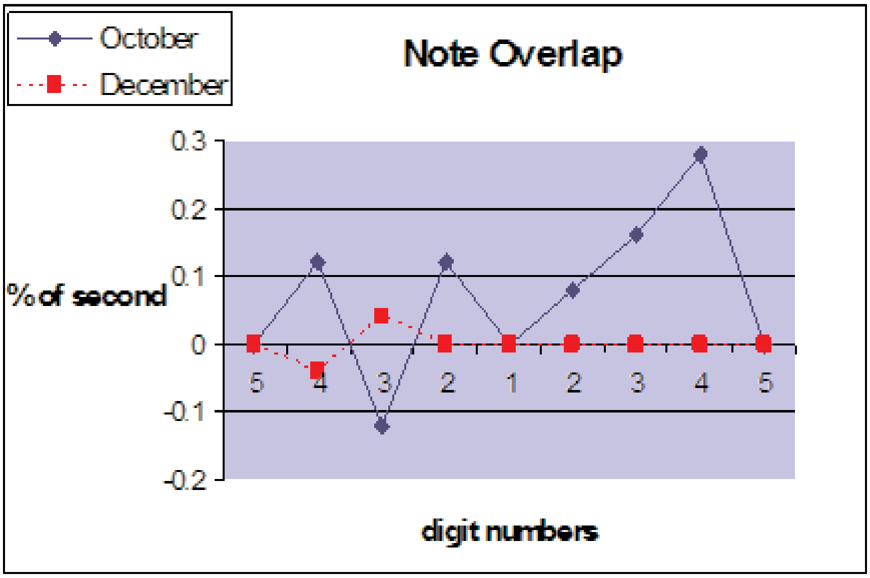

FIGURE 5. Improvement in note overlap between sessions as measured in seconds of real-time piano playing.

can see while playing has been extremely helpful, especially when taken frame by frame in playback. By looking at my hand on the computer screen, it's easier for my brain to get 'inside my hand.' Disklavier playback is helpful as to the evenness of the sounds I am playing and the piano roll shows me my progress.

DISCUSSION

Electromyography and video feedback and analysis provide a tool for teachers and therapists to discover compensatory relationships between fingers and muscles that, to the naked eye, might otherwise go undiscovered. This process takes time and patience on the part of the pianist and instructor/therapist.

This method has been used with other pianists as part of their training but not in a formalized study. The pianists are all college level and reported difficulties in playing certain passages. Initial sEMG readings indicated high levels of tension in the forearm of the affected hand(s), even during periods of rest. Collapsing finger joints were also observed. The

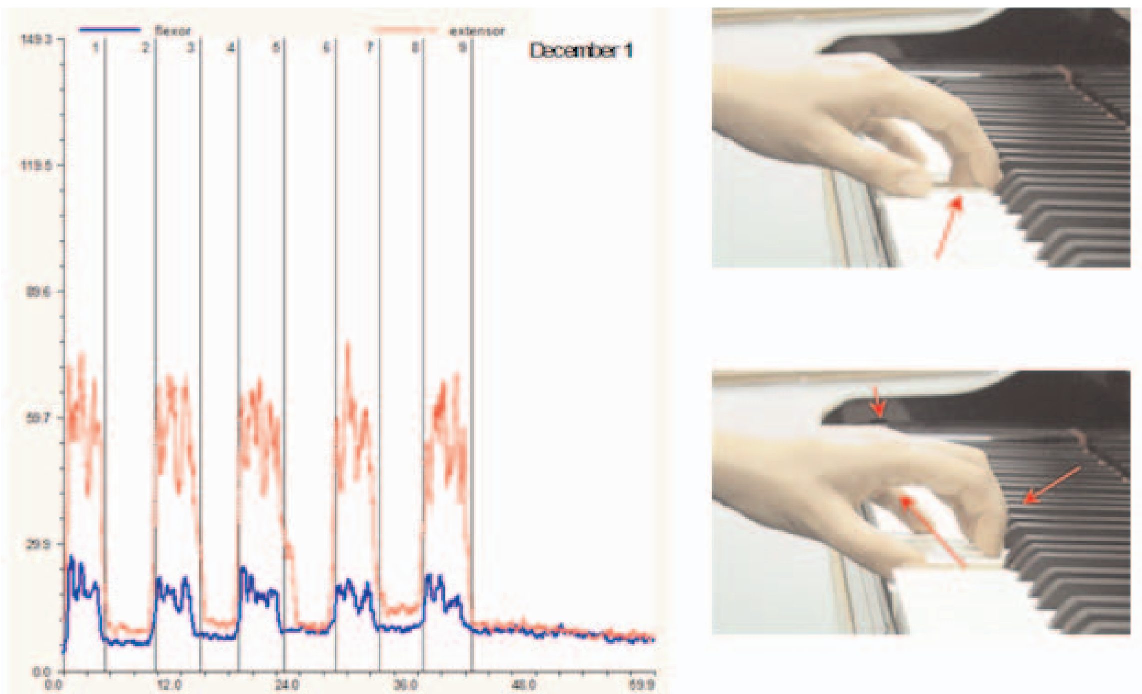

FIGURE 6. Surface electromyography graph of 5-finger exercise performed on December 1. Note that the ordinate, expressed in microvolts, is not drawn to the same scale as in Figure 3. The metric on the abscissa is in terms of seconds.

TABLE 1. **Statistics on the 5-finger Exercises Shown in Figure 3 (October 20) and Figure 6 (December 1)**

Site	*Maximum*	*Minimum*	*Average*	*SD*
Rest phase overall statistics (averaged over 5 repetitions: October 20				
Flexor	48.79	8.66	20.50	3.66
Extensor	99.98	14.71	36.03	5.21
Action phase overall statistics (averaged over 5 repetitions): October 20				
Flexor	101.69	13.45	42.86	4.38
Extensor	208.05	29.87	78.82	4.39
Rest phase overall statistics (averaged over 5 repetitions): December 1				
Flexor	14.25	5.24	8.79	1.21
Extensor	49.70	5.70	13.97	3.17
Action phase overall statistics (averaged over 5 repetitions): December 1				
Flexor	49.93	6.04	16.78	0.59
Extensor	122.78	14.82	51.73	1.90

The units of measurement (µV) to which the numbers refer are described in Figures 3 and 6 and the text.

students had not been aware of hand position until they were given video feedback. One student commented, "This really makes a lot of sense but it's hard to get my fingers to do what I now know they should do." Another student states, "I no longer have pain in my arm when I play. I am more aware of tension in my arm and fingers when I'm practicing. I take breaks and am exercising more." Multimodal biofeedback seems to help pianists in two important ways: (1) to become aware of body alignment, muscle movement and muscle tension, and technical movements and (2) to provide feedback on the sounds resulting from these and any changes in them, particularly changes leading to sought-for improvements in the musical outcomes.[34,35]

CONCLUSIONS

While the medical field identifies technique as an important factor in the physiologic health of musicians, the components of "healthy" technique as opposed to "faulty" technique have not been emphasized to most teachers. Teachers need to become skilled diagnosticians.[36] There is no set position of arms, hands, and body that will apply to everyone. Each student's height; length of torso, arm, and fingers; and physiologic makeup demands its own prescription.

Elucidating the psychomotor complexity of human music behavior has been a daunting research problem. Investigators have been striving to clarify the interplay of external parameters (sights and sounds of performed music) and internal parameters (anatomy, physiology, psychology of each individual).[14] MIDI allows external parameters to be recorded, played back, and measured. Piano roll notation has been demonstrated as an interactive training tool having a noticeable effect on musical performance.[22,23] Using a visual modality in addition to the auditory one for feedback can help in monitoring musical expressiveness in tandem with technical production so that it can be used self-correctively. Video camera-recorded arm and finger motions can be measured and analyzed frame by frame. sEMG allows for objective physiologic monitoring that can help to identify patterns of muscle tension and relaxation during the course of piano performance. Healthy technique, as demonstrated by many professional pianists, involves the ability to relax immediately after depressing the key,[22] thereby making the tension-relaxation cycle more reliable.

These forms of feedback can be used separately and in concert to assist teachers in their awareness, assessment, and treatment of body alignment and muscle tension in developing skill acquisition. Feedback can enhance the transfer of learning to students by bringing their awareness to the coordination of elements of alignment and choreography necessary for technical control of fine motor movement, resulting in improved sound production that otherwise might be unnoticed. Perhaps even more importantly, these scientific feedback techniques can potentially be used to improve some of the current pedagogic methods used in music education.

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