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NEW VIEWS OF PIANO PLAYING THROUGH MOTION ANALYSIS AND MIDI TECHNOLOGY[1]

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This study used motion analysis and MIDI technology to provide immediate feedback on pianists' scale playing and to examine their technical performances in detail. Advances in technology today have made it possible to capture segments of recorded video and analyze them frame by frame, uncovering the finger, hand and arm movements that are occurring at all times, including compensatory movements of other fingers not involved. Scale analysis software was used to analyze performances of scales in terms of velocity, note duration, note overlap, and inter-onset timing. Results suggest that technology-assisted biofeedback can assist pianists in examining technique in performance and in becoming aware of their hand positions and the subsequent sounds produced. Comparison of scale analysis data and motion capture analysis suggests some correlation between hand position and velocity, as well as some correlation between hand position and note overlap. Further investigation is needed to assess if and how hand position affects the level of muscle tension.

Pianists constantly work to improve technique, often repeating the same passage over and over again to get the right notes and to increase speed. Scales are a staple of pianists' practice regimen, often played over and over for extended periods of time at various speeds. As a result, misperceptions can develop by pianists regarding their own playing, in particular, about technical actions and the auditory results. The first question of the study was what misperceptions, if any, piano students might have regarding their performances when they are presented with feedback?[1]

The second question was what useful information on technique and performance could be gained through technology? Hand position and technical performance of students' scale playing was analyzed through motion analysis of finger, hand and arm movement, and recorded MIDI (musical instrument digital interface) data of the performance. Current research suggests that correct body alignment is essential and may be the answer to improved performance and mastery of technique.(Mark, 2003; Sandor 1995) Are students aware of body alignment when they practice? Can all of the intricate movements be seen with the naked eye and understood during performance? It is difficult to monitor the position of one's arms, hands and fingers when playing fast passages? Pianists tend to monitor movements as they are playing–according to their "feel"–rather than visually. Unfortunately, optimal movements not always are analyzed by piano teachers when they teach advanced levels of technique to their students.

Repetitive practicing can result in the pianist becoming disengaged from attentively listening to the sounds produced and from the awareness of the choreography of muscles and fine motor movement involved in production of sound. Complex tasks, such as the refinement of fine motor control programs must be linked with detailed and effective aural analysis skills in high-level musical instrument performance (Riley, Coons & Marcarian, 2005).

Advances in technology today make it possible to capture finger (and other) positions on video and analyze them frame by frame, uncovering the movements that are occurring at all times, including compensatory movements of other fingers not involved. Athletic coaches have made use of this technology for years in perfecting technique in golf, tennis, skiing and other sports.

The ability to monitor one's own performance seems to be an important aspect in the process of musical skill acquisition (Drake & Palmer, 1997). It is generally impossible to gain fine control of subtle motor responses if the feedback of signals arising from these responses is not consciously discernable, and it is difficult to criticize oneself while performing. However, using another modality in addition to the aural mode for feedback can help in monitoring musical expressiveness in performance. The use of visual feedback has been used as an aid for understanding musical expressiveness in performance (Riley, 2005).

Real-time visual feedback offers another and often superior way of monitoring one's performance. Some empirical work shows the influence of real-time visual feedback (Breslin and Juslin, 2003). In a study by Riley and Butler (2001), replication and auditory/visual feedback enhanced pianists' understanding of interpretive nuances. Feedback was provided through a MIDI-equipped acoustic piano and a music software program. A second study (Riley & Coons, 2005) examined more closely the role of piano roll "performance score" visual feedback in improving less advanced students' rhythmic perception of melody. This study aimed to examine detailed auditory and video/visual feedback to provide information about technique in piano performance and feedback for pianists to improve their playing.

Method

Participants

Participants were 6 conservatory level pianists from the Conservatorio Svizzera italiana in Lugano, Switzerland.

Equipment

Disklavier piano. The Disklavier™ is an acoustic piano equipped with optical sensors that measure (a) the time intervals elapsing between key strikes, referred to as Inter-onset Intervals (IOIs), (b) the velocity of each strike in determining dynamics, and (c) the duration with which each key is held down. These parameters are recorded in SMPTE (Sound and Motion Picture Television Engineering) time code in hours, minutes, seconds, and frames at a rate of 25 frames each second. The data can be read through the music sequencing software. IOT measurements of the notes can be deduced by subtracting the onset of each note from the onset of the previous note.

Digital video recording. Linked through a synchronization box, the MIDI-equipped piano is connected to the video camera, and the time code from the video is striped simultaneously onto the MIDI sequence. MIDI keyboard recordings and videos can be played back simultaneously, providing feedback on sound, body alignment, and hand and finger position at the keyboard from perspectives that pianists do not hear and see while performing–thereby revealing technical flaws that the pianists may not have been aware.

Motion capture software. Since the playback of the video recording in real time does not help pianists identify precisely what hand and finger movement(s) they may be creating or adding to technical problems, Dartfish™ 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 visually undetected during performance.

Music sequencing software. Emagic Logic™ was used for recording and MIDI-files. The piano roll graphs displayed in the sequencing software are sound pictures of the accompanying MIDI tracks. The piano keyboard is displayed vertically to the left on the graph, and the horizontal bars indicate the keys played, The colors of the bars reflect dynamics: ranging from deep purple for pianissimo, dark blue and blue for piano, teal and green for forte, to yellow and red for fortissimo. The MIDI tracks and piano roll graphs visually depict nuances of interpretation such as legato, staccato, crescendo and decrescendo. Students actually see a performance score or map while listening to a performance.

First Session

Scales were performed on a MIDI equipped piano which was connected to a computer. Subjects had the opportunity to warm up and get used to the keyboard. For the test, sequences of 10 to 15 C major scales were played over two octaves (C2-C4) in both directions, upward and downward with the right hand. Subjects were asked to play in legato style and with a crescendo in the ascending scale and with a decrescendo in the descending scale. Fingering was according to the regular C major fingering (1 – 2 – 3 – 1 – 2 – 3 – 4, etc.). Scales were played in 16th notes, and the tempo was standardized at 80 beats per minute for a quarter note and then 120 beats per minute, paced by a metronome. Left hand scales were not analyzed.

All playing was recorded simultaneously on piano and video recorder. Participants received feedback on their performances in three ways. First, they listened to their recorded track; second, they viewed the piano roll of their performance on the computer screen while listening to their playing; and third, they viewed the videotape of their hands while hearing their performance. After each type of feedback, the participants were asked for their comments. They were asked what they thought of their legato playing and their use of dynamics. A discussion followed.

Second Session

Participants reviewed their first performances with each of the feedback methods. They were then asked what they would like to change in their performances. The procedure from session one then was repeated: Sequences of 10 to 15 C major scales were played over two octaves (C2-C4) in both directions, upward and downward, with the right hand. Subjects were asked to play in legato style and with a crescendo in the ascending scale and with a decrescendo in the descending scale. Their objectives were to improve dynamic range and legato technique.

Data Analysis

MIDI data of all performances were recorded on the Disklavier piano. Video clips of participants' hands were recorded simultaneously during performances. Students' self evaluations of their performances were recorded before and after they received three forms of feedback: aural only, aural and piano roll score, aural and video. Performance objectives for session 2 were included.

A MIDI-based Scale Analysis Software was used to analyze student performances: key velocities (an indirect measure of loudness), tone durations (time between note onset and end of note), inter-onset intervals (time between note onsets of two subsequent notes) and tone overlaps (time between note onset and end of preceding note) for all individual notes of the scales. Standard deviations of all four parameters were calculated for each scale. Finally, the mean standard deviations of the four parameters of all scales of a sequence were yielded. Scale analysis was done separately for ascending and decending scales. The very last note of the scales (upward note c2, downward note c) was excluded from analysis in order to avoid distortion of results (last notes were frequently elongated according to the pianists' musical taste). Scales containing wrong notes or other mistakes regarding the order of the C major scale were excluded entirely from the analysis. A minimum of 10 correct scales was required for the analysis of a sequence (Jabusch et al, 2003).

Data from sessions 1 and 2 were compared to track changes in dynamics and note overlap. Analysis of students' technical movements was performed using Dartfish motion capture software.

Results

Legato playing is associated with minimally positive overlaps. In the preparation phase of finger crossover there was a consistent finding of gaps between the notes in all six students. There was significantly little or no overlap in the 3rd and 4th fingers at the 3-1 ($M = -21.5$, $SD = 8.83$, mm = 80;

M = -26.2, SD = 10.5, mm = 120) and 4-1 (M = -17.2, SD = 15.5, mm = 80; M = -17, SD = 15, mm = 120) cross-under in the ascending scale, and little or no overlap in the thumb at the 1-3 (M = 3.3, SD = 11.6, mm = 80; M = -13.5, SD = 11.3, mm = 120) crossover in the descending scale. These means are averaged across the six students. Two of the students had heavier overlaps than they had realized. The other four had gaps between notes, at other than the crossovers, especially the beginning of the ascending scales and at the ending of the descending scales. Overlaps from 5-4-3 in the descending scale were also consistent.

With auditory feedback from the Disklavier, all six students heard that there was not as much dynamic contrast as they had perceived while playing. Results on velocity from session 1 show that the crescendo in the two octave upward scale occurred within the first octave, arriving at a plateau for the second octave. The decrescendo scale began at a slightly lower velocity with an increase on the first few notes. The first octave stayed within the same velocity range and most of the decrescendo occurred in the second octave.

Feedback from the piano roll made students aware of unevenness of notes and gaps between notes. All students were surprised by the video feedback. Scale analysis indicates that although they made decisions to try and change their dynamic scale, the amount of note overlap for legato and/or finger position performances did not significantly change from session 1 to session 2.

Comparison of scale analysis data and motion capture analysis suggests some correlation between hand position and velocity: Lowering the hand while playing the thumb correlated with an increase in velocity; the extra force was exerted on the key with the movement of the hand. Analysis also suggests some correlation between hand position and note overlap: For students with hand position keeping fingers close to keys, there were larger overlaps between notes than students with fingers raised and curled where there was less overlap between notes (see Figures 1 and 2).

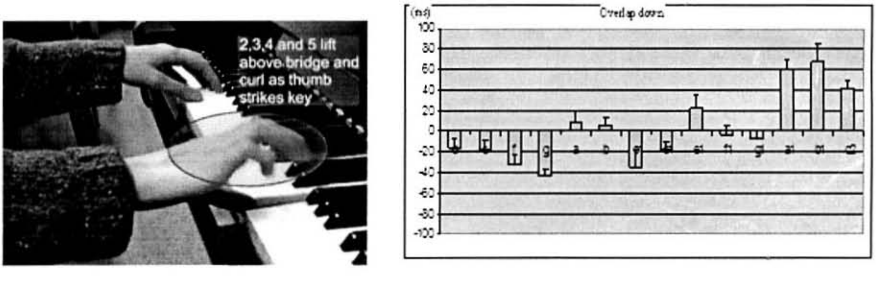


Figure 1. Raised and curled fingers; less overlap.

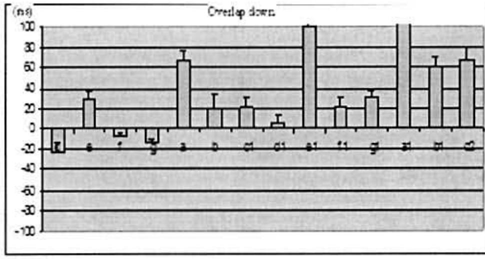


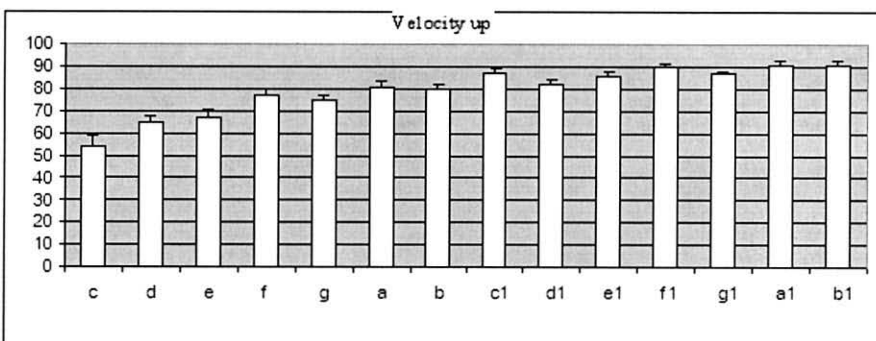
Figure 2. Fingers close to keys; increased overlap.

Case Study

Here is an example of how motion capture and MIDI scale analysis can critically analyze technical performance: In his first session, Student R commented on lapses of concentration and accents created by the thumb. Midway through the performances he thought the scales lacked sufficient dynamic contrast for crescendo and decrescendo; he thought that he had become distracted, but said that his legato was good. He commented that playing the ascending scale with a crescendo was more difficult than the descending scale with a decrescendo. He perceived that his thumb was creating accents (see Table 1).

Table 1

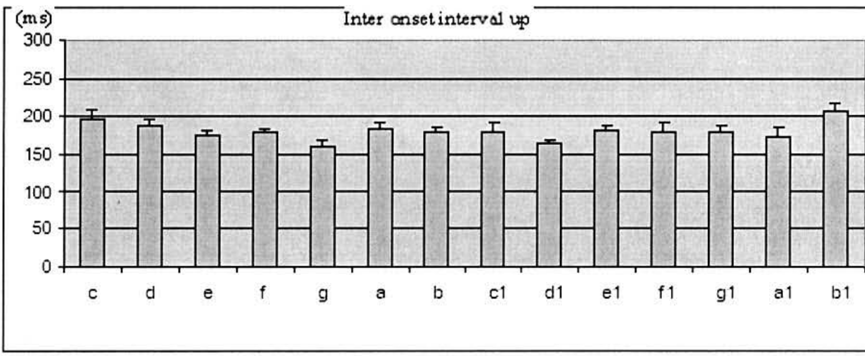
Velocity of Notes in Ascending Scale Session 1, mm = 80



Velocity increased from 54 to 80 in the first octave but increased by only 10 ms in the second octave, beginning with a jump to 87 on c1 and reaching 96 on c2. Table 2 substantiates the perceived accent with the

Table 2

Inter-onset Results for Ascending Scale, mm = 80



thumb, as the thumb hit f with a jump in velocity to 77, from 67 on e with the 3rd finger, and a drop to 75 on g played with the 2nd finger; and again there is a jump on c1 with the thumb to 87, from 80 on b with the 4th finger; and then the 2nd finger hit d1 with a drop to 82. In both cases, the unintended accent occurred on the weak part of the beat. The student was playing four 16th notes per beat and the thumb played the last 16th note of each group. Articulation for groupings of four 16th notes dictates a pattern of strong-weak-medium-weak. However, the increased velocity with the thumb caused the last note of each group to be the strongest.

Inter-onset results for the ascending scale played at metronome marking (mm) of 80 show that less time elapsed between the thumb and the second finger (notes g, d1) after the cross under (Table 3).

Overlap results for the ascending scale played at mm = 80 show negative overlap for the 3rd finger at the cross under (notes e, e1) as well as the 4th at the cross under to the thumb (note b). Negative overlaps indicate a lifting of the finger or fingers creating a break in the smooth legato line. There is little or no overlap at the beginning of the scale (notes c, d, and e).

Video Analysis. The hand is close to the keys and the fingers are curled as the thumb depresses the key (Figure 3, position 1). The hand is close to the keys and the fingers are curled as the 3rd finger depresses the key (Figure 3, position 2); there is little room for the thumb to cross under, therefore the 3rd must lift up to accommodate the thumb. As the thumb crosses under, curled fingers 3, 4, and 5 extend and lift above the knuckles (Figure 3, position 3). The key is hit with the thumb in a flat position, lowering the hand and wrist – the accent is unavoidable with this type of movement. Student R needs to keep bridge of the hand above fingers and strike with the thumb at an angle, in keeping with the alignment of its resting position from

Table 3

Overlap Results for Ascending Scale, mm = 80

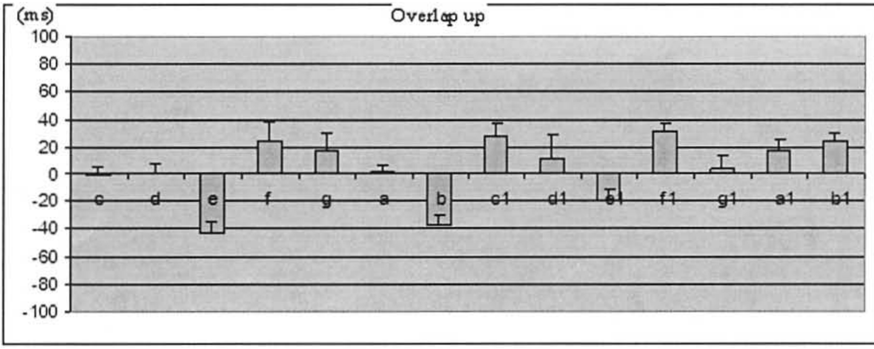


Figure 3. Hand position 1, 2, 3.

the bridge. On the charts, the velocity for the 2nd finger is less than the thumb after the cross under. The thumb might not be perceived as an accent if the following notes did not lessen in velocity.

The 2nd finger scratches key upon release; as the 3rd plays, the last joint collapses (Figure 4, position 4); this unnatural position (from the resting position of the hand) causes tension in the other fingers; the 5th finger raises and curls above the bridge. As the 4th finger is depressed, the 3rd lifts slightly and curls under (Figure 4, position 5); the 2nd and 3rd fingers are above the bridge, allowing the hand to collapse, leaving little space for the thumb to cross under. To make room for the thumb, the other fingers extend up above the bridge, although they are still in a curled position (Figure 4, position 6). The velocity chart shown in Table 1 indicates a greater velocity on the thumb at the beginning of the second octave. On the overlap graphs, the 4th finger is released before the depression of the thumb.

As the 2nd finger plays again, the 4th and 5th rise and curl (Figure 5, position 7). Again at the cross under, the thumb depresses the key in a flat position and the other fingers lift above the bridge (Figure 5, position 8). There is quite an extension of the fingers here. Figure 5 position 9 is almost identical to the earlier photo of the 3rd finger depressing the key; the 2nd is tucked under the hand and the 5th is raised high above the bridge.

Figure 6 position 10 shows that as the 4th finger depresses the key, the 2nd and 3rd fingers curl. The 5th finger extends out straight, preparing to strike. As the 5th finger depresses the key, the 3rd, 4th and 5th extend above the bridge and curl (Figure 6, position 11). There appears to be a lot of tension in the fingers.

Figure 4. Hand position 4, 5, 6.

Figure 5. Hand positions 7, 8, 9.

Figure 6. Hand positions 10, 11.

Discussion

In teaching students, it is important to explain what happens on a sensory level. It is the balancing of auditory, tactile and visual perceptions that allow one to "speak" the language of music through an instrument. Technology assisted biofeedback can assist in the balancing of auditory and tactile sensory awareness in music performance.

Often it is difficult to detect note overlaps and gaps while playing. In auditory perception, the onset of a subsequent note may mask the detection of the ending of the preceding note. This interaction can take place as tonal masking (in positive overlaps with a masked detection of the preceding tone after onset of the subsequent tone) and backward temporal masking (up to 50 ms before onset of the subsequent tone, Yost, 2000). This could result in impaired perception of overlapping notes and gaps between notes. Evenness of the overlaps is perceived only to a limited extent within this range and therefore it is not an aim of practicing. Student A's definition of legato was a succession of sounds without time gaps between them.

Seeing the keys move while hearing playback provided feedback on legato playing. With feedback from both the piano roll feature and Disklavier playback, the students became more aware of the inconsistencies in their legato playing. Student F was surprised to see the overlapping of fingers 3-4 in the louder section. Student L noticed for the first time which fingers were responsible for the uneven dynamics. She noticed a large overlap between some fingers and asked if overlaps could be related to control of dynamics. Student P observed that the beginning of scales were not legato. The researcher asked what additional information can be gained from looking at the piano roll. Student P said he understood more about legato and dynamics. Students felt that the Disklavier provided auditory proof and the piano roll provided visual proof of their playing that was irrefutable. It is often difficult to perceive the scope of a crescendo or decrescendo while playing. Disklavier playback provided immediate feedback of sounds produced.

Video Feedback

Feedback from the video with Disklavier playback helped students understand hand and finger movements of which they were unaware. When shown the video, student A exclaimed "aiuto!" She did not want to see her hand, saying it moved too much. There was excess movement in other fingers when one finger struck the key. Student F commented that there were unwanted accents and that she had to make an effort at playing an even tempo when playing louder. This study helped her to recognize this trait. Student P realized fingers 3-4-5 were not functioning independently.

Student A commented that when one finger presses a key down, other fingers tend to go up for no reason. Figure 7 shows the lifting of the 5th finger in the descending scale as the 3rd finger hits the key; and the 4th overlaps with a delayed release.

Student F commented that she had trouble with her fingers while playing forte. Video analysis seems to indicate more problems with the 2nd finger not releasing, thus causing a large overlap (Figure 8). Analysis of muscle tension with surface electromyography (sEMG) might indicate an overuse of tension which could result in the resulting feeling of weakness while playing forte.

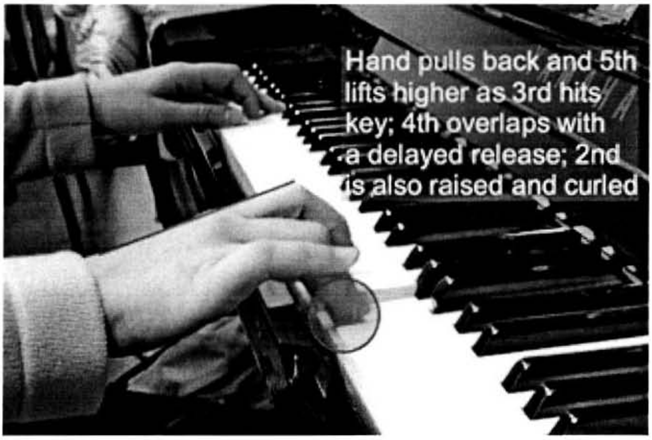


Figure 7. Student A's Hand position.

Figure 8. Student F's Hand position.

Individual differences in technique and hand size accounted for the large degrees of variability in overlap. All students were surprised to see their hand positions and the movement of their fingers. Only one of the six students stated that she had worked on hand position and technique with a former teacher for several years. The other five commented that they needed to be more aware of their hand position while playing. They felt that they should try to correct raising and curling of the fingers, especially in finger movement that seemed to be compensating for the engaged finger striking the key.

After receiving feedback on their playing, students commented on how they would like to improve their performances in session 2. However, it is difficult to change motor habits quickly. The intricate interplay between muscular-skeletal physical movements and cognitive messages of the brain are complex. Although musicians may become aware of faulty or careless technical movements, the problem probably originates in a higher center in the brain. Unconscious bad habits cause a change in normal movements of many other muscles in the upper body (Tubiana, Chamagne, Brockman, 2005). Technical movements are personal musical expressive gestures and are difficult to change without slow, careful work and feedback. In session 2, as the number of repetitions increased, old motor habits returned. Auditory feedback from an instrument such as the Disklavier is important as well in order to help pianists hear the musical result of their technical gestures. Student R commented that he didn't really pay attention while practicing scales; it was just a morning routine.

While many of the great pianists played with hand positions that looked unnatural, many pedagogues agree on a few general guidelines regarding hand position. The position should be natural, as the hand shapes itself in a resting position. Correct motions should be based on natural, inherent hand, wrist and arm reflexes. Bruser (1997) emphasizes the importance of a flexible wrist, but it should not drop below the keyboard. Magrath (Clavier, 1994) cites the pushing of weight into the wrist as opposed to letting the weight move through the wrist to the fingers, thus pushing excess weight into the keys and curving the fingers unnaturally and creating potentially harmful movements. Flattening of the arch of the hand at the knuckles creates tension in the forearm and fingers (Brown, 2000). Lifting fingers high off keys involves an overuse of the extensor muscles of the fingers and not enough use of the flexor muscles (Brown, 2000). Motion analysis of the hand position showed unnatural curling of fingers in several students.

According to Sandor, fingers and arms are supposed to complement, not to substitute for, each other. Obviously relying on the fingers alone causes overwork in the forearm muscles, while the use of only the wrist and arm produces sloppy, inaccurate, and inarticulate playing. Further investigation would need to be done to assess if and how hand position affects the level of muscle tension. Overwork of the forearm muscles could result in stress injuries. Previous studies (Riley, Coons & Marcarian, 2005) indicate a correlation between hand position and muscle tension.

Slow, careful analytical work with auditory and video feedback in practice sessions would be beneficial in correcting hand position and evenness of legato note overlap. Motion analysis allows for comparison of frame by frame playback to the original video for tracking of improvement. The use of the Disklavier recording and playback provides feedback on sound as well as the overlapping of keys, because the keys move during playback.

Conclusions

Biofeedback brings one's awareness to problems that he or she was not aware. Auditory and video/visual feedback can provide far more detailed information about piano performance. Motion analysis has been widely used in the sports communities for years. In fact, it is a staple for many golf and tennis professionals. There are many possibilities for its continued use in music performance. Most importantly, however, is how this information about technical production is linked to auditory understanding through playback of the musical performance on the Disklavier.

To retrain technical movements, the student must work slowly in order to become aware of all movements in the hand and fingers. Simple exercises, such as finger isolation, 5 finger patterns, a one octave scale or arpeggio, are best for warmup. Teachers can assist students in becoming aware of the amount of tension in their shoulders, elbows, forearms, wrists and fingers while playing slowly. While tension is important for striking the keys, it should not be used in excess and release points must be found in music passages. It is very important to incorporate feedback on sound produced, for technique is only the means to the expression of the music, not an end in itself.

As instructors of refined motor control, teachers need to become skilled diagnosticians. 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 physiological makeup demands his or her own prescription. In addition, the components of optimal healthy technique must be emphasized to teachers as well as students.

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Footnote

[1]This project grew out of a collaborative study organized by the Dipartimento di Ricerca e Sviluppo at the Conservatorio della Svizzera italiana exploring the use of computer technology in piano practicing as well as the relationship between the pianist's perception of his or her playing on the one hand and the sound's physical reality on the other.