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SIGHT-READING VERSUS REPERTOIRE PERFORMANCE
ON THE PIANO: A CASE STUDY USING HIGH SPEED MOTION
ANALYSIS

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ABSTRACT:

The purpose of the study was to examine whether differences exist in the motions employed by pianists when they are sight-reading versus performing repertoire and determine whether these differences could be quantified using high speed motion capture technology. A secondary question of interest was whether or not an improvement in the efficiency of motion could be observed between two sight-reading trials of the same musical excerpt. This case study employed a six digital infrared camera system (Motion Analysis, Inc.) to capture the motion of pianists playing two trials of a repertoire piece and two trials of a sight-reading excerpt. Angular displacements and velocities were calculated for bilateral shoulder, elbow, wrist, and index finger joints. The findings from this study demonstrate the usefulness of high speed motion capture technology for analyzing motions of pianists during performance.

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Pianists are frequently confronted with situations that necessitate adequate sight-reading skills. This widespread need for sight-reading at the piano may be due in part to pianists' participation in collaborative music-making. The size of the piano literature also contributes to the need, as the repertoire is so voluminous that no one player can be familiar with all the solo and collaborative pieces written for piano. Recordings of piano literature tend to be restricted to the most well-known and familiar pieces. Recordings of pedagogical piano literature, in particular, are sparse. Professional pianists often sight-read in the course of collaborating with other musicians or accompanying choral ensembles. The nature of sight-reading varies widely. The pianist might have a few minutes to examine a score, or might have to read the music with little or no preparation. In any case, the sight-reading task may be viewed in direct contrast to a repertoire task, in which the pianist has engaged in weeks and often months of cognitive and physical training, thus gaining a high level of familiarity with the music being performed.

Demands of Sight-reading

Sight-reading performance entails a number of demands that can be distinguished from those inherent in the performance of practiced repertoire. Basic elements that must be attended to during sight-reading performance include:

1. rhythm: meter, duration, patterns, accentuation
2. melody: pitch, direction, movement (skips versus leaps, etc), and
patterns
3. harmony: chord structure, chord progressions
4. context: articulation, expressive markings, musical structure and form

In addition to these basic constructs there are also more subtle cues-- such as maintaining balance between the hands or attention to performance practice-- embedded in the music that may or may not be rendered in a sight-reading attempt based on the experience and musical sophistication of the instrumentalist.

Prerequisites for successful sight-reading included the ability to recognize musical patterns, generate a large-scale performance plan to govern performance of the piece as a whole, and learn to anticipate how the music continues (Lehmann and Ericsson, 1996). In addition to perceiving and decoding aspects of the score, successful readers anticipate problems while continuing to observe musical markings and evaluate sight-reading execution to correct the performance as necessary (McPherson, 1994).

Piano sight-reading also poses a visual challenge. Looking at the musical score must be balanced with the need to look at the hand and fingers to accurately place them on various parts of the keyboard in order to play correct pitches. The pianist can easily lose his/her place in the score as the eye moves and refocuses. In contrast, rehearsed performance typically negates the visual difficulties of score reading as memorization is common practice. Performance of practiced repertoire allows for free recall of musical materials and physical mastery of requisite motor skill patterns. Each time a repertoire piece is practiced, the pianist makes more inferences about correct pitches and other musical details (Lehmann & Ericsson, 1996).

Underlying all of these cognitive and physical considerations is the daunting constraint of sight-reading with continuity, in “real-time,” without stopping to decipher the written score or correct mistakes. Maintaining a continuous rhythmic pulse is

paramount. The musician must keep playing during sight-reading, even if s/he executes notation improperly.

Studies conducted regarding sight-reading ability to date have fallen into three broad categories:

1. Cognitive/Perceptual: including eye movements, perception of notation and other aspects of the score, and the influence of visual and auditory feedback
2. Factors affecting success in sight-reading achievement, including differences pertaining to specialization among pianists
3. Educational/Pedagogical approaches, which focus on sight-reading acquisition or improvement with help of specific instruction or pacing devices.

The literature reviewed for the present study focused on the first two categories of sight-reading study.

Cognitive studies on sight-reading to date have primarily focused upon determining what internal processes successful sight-readers use in comparison with those musicians who are less skilled or less experienced at the sight-reading task. Studies in this area to date have focused primarily on eye movements (Sloboda 1974, 1977; Furneaux & Land, 1999), pattern recognition and “chunking” musical details into larger perceptual units (Goolsby, 1994; Waters & Underwood 1998), and perception of musical notion within a larger context (Waters, Townsend, & Underwood 1998); Halsband et al, 1994; Sloboda, 1993). Cognitive/perceptual studies have addressed the processing work done by the brain during the sight-reading task, rather than examining physical motions.

While motor execution has not been the primary focus in the aforementioned types of studies, several studies focusing on cognition during the sight-reading task have

considered motor patterning outcomes in relation to cognitive processing. There is some merit to the traditional and intuitive pedagogical notion that the best way to improve sight-reading ability is to engage in sight-reading activity. Both performance accuracy and consistency of fingering correlate positively with expertise (Sloboda, 1998). Expert piano sight-readers develop rule-governed patterns of motor response in their fingers that are utilized upon recognition of familiar visual notational patterns. As expertise increases, musicians are able to combine movements into variable patterns that appropriately execute musical notation. Skilled motor performance in any human endeavor rarely consists of rigidly programmed motor sequences where each individual movement arises invariably and inflexibly from the prior movement. Shaffer (1981) noted that expert pianists were able to develop a mental plan that specifically addressed the intended sight-reading outcome and employ a flexible motor programming system that efficiently enacted the required muscular contractions. It is thus apparent that skilled sight-readers have better developed and more flexible motor programming patterns when sight-reading at their instrument than do novice sight-readers.

Even for those players with this advanced motor programming ability, it is likely that sight-reading is more physically awkward than the performance of repertoire that has been previously practiced. In their examination of pianists learning new repertoire, Halsband, Binkofski, and Camp (1994) found that as players moved from the beginning stages of working with a piece to more advanced interpretive and expressive phases, the perception of the task changed. Motor skills were less efficient during the early learning phases of a piece. As pianists began to perceive progressively larger metrical groupings as a result of practice, their motor patterns became increasingly more efficient. Just how

these motor sequences become ingrained in pianists or other instrumentalists remains a question for further research.

As can be seen from a review of the literature, physical motion during sight-reading has not been a focus of research. Many pianists and piano pedagogues have asserted that they find the experience of sight-reading to be more physically taxing than performing or practicing repertoire pieces, and further suspect that excessive sight-reading can expose pianists to injury. William Westney (2003) encapsulated this belief, saying: “there is certainly a direct link, though it has been little discussed, between high-level sight-reading and performance injuries.” This widespread perception underscores the unique challenges inherent in sight-reading, which until now, have not been investigated from a quantitative scientific perspective. The purpose of the present study was to identify whether the use of motion capture technology can identify quantifiable differences in the motions made by pianists when sight-reading versus performing practiced repertoire. If these differences do exist, the goal is to describe these differences and draw conclusions regarding motion efficiency based upon the quantified data. At present no normative values exist to describe efficient motion at the piano in either sight-reading or repertoire performance. This study represents an initial step toward this end. A secondary question of interest is whether differences in motion can be observed from one sight-reading attempt to the next, which may demonstrate adaptations of motor skills resulting from a single reading of a musical excerpt.

METHODOLOGY

The participant signed an informed consent according to university Institutional Review Board guidelines and then completed a questionnaire that inquired about recent pieces performed and lifetime practice habits. Realizing that levels of pianistic experience do not correlate with age, nor does the level of sight-reading match the ability to sight-read proficiently, several crucial accommodations were made to allow for these variables. The terms pedagogues typically apply to experience level of pianists—“beginning,” “intermediate,” and “advanced” —do not have absolute meaning. Thus, for the purposes of this study, it was necessary to place some parameters around these terms. Repertoire level was designated as “elementary”, “intermediate”, or “advanced” by making arbitrary distinctions within the leveling system employed by the Royal Academies of Music system. A “beginning” student was defined as playing in the first two levels of any method book, or below level 3 according to the Royal Academy of Music; intermediate levels were defined as encompassing levels 4-8; advanced level was defined at anything at level 9 or above. The subject chosen for the case study was a 23 year old female. She was designated as being of “advanced” experience level since her repertoire, Chopin’s B-Flat Minor Scherzo, fell above level ten within the Royal Academy categorization system. She reported taking piano lessons for 19 years, and was still taking lessons at the time of data collection. Her estimated lifetime practice total was 8,944 hours.

There is a wide disparity of sight-reading abilities even among expert pianists. Since sight-reading ability and repertoire level rarely correspond, during the participant’s initial visit, a pretest was given to determine the level of sight-reading ability according to specific criteria. In order to determine the subject’s unique sight-reading level, two sets of sight-reading materials were prepared: one for the pre-test, and one for data

collection. Each set contained 15 levels of sight-reading of increasing complexity and difficulty. To ensure that the sight-reading encountered during data collection was *true* sight-reading (i.e. had never been encountered), the sight-reading excerpts that participants played during the pre-test was *different from* but *equivalent to* data collection sight-reading. Equivalency of the two sets of sight-reading was verified by two additional piano pedagogy experts at peer institutions.

During the sight-reading pre-test, a ten point Likert scale was used to determine the subject's unique sight-reading level. Elements measured by this scale included the subject's ability to:

- Maintain a steady, consistent pulse
- Play accurate pitches
- Observe tempo
- Employ reasonable fingerings
- Observe articulation and phrasing
- Observe dynamics and other musical markings
- Capture musical mood
- Use appropriate pedaling

The subject played multiple examples of varying difficulties until her score on the criteria listed fell within the range of 6-9 on a 10 point scale. Using these mid-range measures helped the sight-reading task mimic real life—the sight-reading was playable yet maintained the element of challenge. Since the participant had to play numerous excerpts to make a determination of sight-reading level, the pre-test was done on a separate day from data collection, to ensure that fatigue from these numerous readings would not negatively impact data collection.

Data was collected in the Movement Sciences Center in the Institute for Rehabilitation Sciences and Engineering at Madonna Rehabilitation Hospital in Lincoln, Nebraska. In order to capture the motion of body segments, 20 reflective markers were

placed on selected anatomical landmarks of the torso, right and left arms, and index fingers. Since placing markers on each finger would have been cumbersome and difficult for the infrared cameras to discriminate, the index finger was chosen due to its continuously active role during piano playing. A six camera digital infrared optoelectronic system (Motion Analysis Inc) sampling at 120 Hz was used to capture the pianist's motions during performance.

Few studies have employed high speed motion analysis to analyze the motions of musicians. Shan et al (2004) used motion capture technology in conjunction with surface electromyography and biomechanical modeling to study motions made by violinists while playing. Their findings demonstrated how information from multiple modes of assessment including surface electromyography, high speed motion capture technology, internal load analysis and biomechanical modeling, could be integrated to provide a fuller understanding of violinists' motions. The present study is the first to apply motion capture technology to the study of pianists.

The subject performed two separate trials of two tasks of approximately two minutes apiece: these tasks consisted of a sight-reading excerpt, and a "performance-ready" repertoire piece. The subject performed the same repertoire and sight-reading excerpts for both trials of each task. The order of the two tasks was randomly determined through the use of a coin toss. Upon being presented with the sight-reading excerpt during data collection, the subject was instructed to begin playing immediately, with no preparation time. The participant selected her own repertoire—the only stipulation was that it should be "performance ready". While memorization was optional, it was

encouraged as it is this is accepted performance practice among pianists. The subject played her repertoire selection by memory.

Results of Case Study

The repertoire piece played by the subject for both repertoire tasks was the Chopin Scherzo in B-flat Minor Op. 31 (**Figure 2**). She played from the beginning of the piece, for a duration of 2 minutes. The sight-reading excerpt she played was the second movement from Judith Lang Zaimont's *Suite Impressions*, entitled "Jazz Waltz." (**Figure 3**), and had not previously been encountered by the subject.

Angular velocity and angular displacement data were examined for the following joints: shoulder, elbow, wrist, and index finger. Angular velocity refers to how fast the marked body segments flexed-extended within a task, while angular displacement indicates how far those segments moved (range of motion).

For both angular velocity and displacement, the minimum and maximum values for each trial of both repertoire and sight-reading were identified for each data set. Subsequently, these two values were subtracted for each data set providing a range of values for these two variables. This subtraction prevented a limited evaluation of the data by examining just the maximum or the minimum value, which has been identified in the biomechanical literature as inadequate (Stergiou, Buzzi, Kurz & Heidel, 2003; Stergiou, Bates & James, 1999). Angular displacement values provided the maximum actual range of motion. Increased values indicated a large amount of movement in terms of flexion-extension at the joint. Similarly, angular velocity provided the maximum range of values present in the data set. Increased values indicated faster movements in terms of flexion-extension at a joint. The mean value of the angular velocity maximum range and of the

angular displacement maximum range of motion was then determined for each repertoire and sight-reading trial (R1, R2, S1, and S2).

Angular displacements used by the subject are displayed in **Figure 4**. The means of all the joint angles were combined to express a composite mean that is descriptive of the trial in general. The subject used a *greater* range of motion in both her repertoire and sight-reading examples from the first trial to the second trial. The composite mean for angular displacement during the repertoire trials increased from 48.895 to 49.5325 on the left side, and from 60.8975 to 66.805 on the right side. Similarly, the composite mean of angular displacement during sight-reading trials increased from 31.64 to 35.3525 on the left side, and from 37.24 to 39.9475 on the right. The subject used less movement overall for the sight-reading in comparison with her repertoire piece. In examining the composite angular displacement means for the right side, there is a difference between repertoire and sight-reading trials of 23.6575 degrees for the first trial (R1 compared to S1), and an even larger difference of 26.8575 degrees in the second trial (R2 compared to S2). This finding is interesting because the keyboard *range* of the sight-reading example is roughly equivalent to the repertoire piece, requiring the same degree of motion to place the upper body over the piano keys. However, the repertoire piece (Chopin Scherzo in B-flat minor), employs more *frequent* changes in position with *both* arms. For example, in the introduction, both arms are positioned to the left (bass) side of the keyboard and are then rapidly displaced to the upper registers of the piano (**Figure 2**). A third observation is that the pianists' movements on the right side of her body were higher. This finding may demonstrate right hand dominance.

The most significant finding with regard to the angular displacement data is that in *both* trials of sight-reading, the finger used almost double the motion of the other three joints. For example, in the first sight-reading trial (S1) on the right side, the subject moved her index finger 64.75 degrees, while the shoulder, wrist, and elbow only moved 23.59 degrees, 22.72 degrees, and 37.9 degrees respectively. This is not the case in the repertoire trials, where the movement of the elbow equaled or exceeded the movement of the finger. In the first trial of repertoire, the elbow moved 76.74 degrees while the index finger moved 65.54 degrees. Since forearm movement as it lines up with individual fingers can be deduced from the motion of the elbow in space, this finding demonstrated that while sight-reading, the subject used more independent finger motion. While playing the repertoire excerpt, the subject used more coordinated motion patterns involving the forearm.

Several significant observations were also made in this case study regarding angular velocity, or the speed at which the identified joints were flexing and extending (**Figure 5**). In the sight-reading task, smaller velocities were observed at all joints in comparison with the repertoire trials, which relates directly to the slower tempo of the sight-reading excerpt compared to the repertoire excerpt. In both the sight-reading *and* the repertoire tasks, velocity increased as it moved from the top of the arm to the tip of the finger. This finding reinforces what piano pedagogues have long asserted—that the motion of the arm in piano playing demonstrates a “whip-like” motion. The most interesting finding in relation to angular velocity is that while velocity from the first repertoire task to the second repertoire task did not change markedly, there *was* a definite increase in velocity from the first sight-reading task to the second sight-reading task. This

finding was not a function of tempo, which remained roughly the same from S1 to S2, but indicated the subject's adaptation to task demands. The increase in velocity in the left hand, is notable because this particular sight-reading excerpt required the left hand to locate bass notes that are isolated by register. The subject improved her velocity in her left hand by 72.5475 degrees per second from the first to second sight-reading trials (S1 to S2). Thus, the greater velocity used in the second trial indicated that the subject gained some level of neuromuscular familiarity with the sight-reading excerpt from a single reading. This last observation is also bolstered by the angular displacement findings. In comparing S1 to S2, there was an increase in flexion/extension angles at all the joints, which would tend to show a greater coordination between all the segments of the playing apparatus rather than over-reliance upon finger motion as previously discussed. Both of these observations support the conclusion that this subject improved her motion efficiency with only a single reading of the sight-reading excerpt.

CONCLUSIONS

Initial findings from this case study demonstrate the efficacy of using high speed motion capture technology to study the movements made by pianists in real time. Piano playing has been associated with a high incidence of injury (Manchester, 1988; Sataloff, Brandfonbrener, and Lederman, 1991). While the exact etiology and pathology of injury development remains largely unknown, it is likely that a number of factors contribute to injury development. Factors that have been identified include lifestyle/behavioral factors, a sudden increase in the time and/or intensity of practice, change in playing technique, and intrinsic factors such as size, strength, muscle tone, flexibility, and genetic predisposition toward injury (Fry, 1986; Brandfonbrener, 1988). While technique may be

less influential than genetics, it is at least a controllable factor. Exploration of piano technique using objective measurement tools, such as high speed motion capture technology, allows for detailed examination of pianists' motions, offering data beyond that visible to the naked eye of the piano teacher. Use of high-speed motion analysis can help piano teachers identify potentially problematic motions in piano technique and enable them to make more exact pedagogical recommendations to students that may help them maximize their motor efficiency at the piano and avoid potentially deleterious movements.



Figure 1: Instrumentation for Data Collection.

Figure 2: Excerpts from the subject's repertoire piece, Scherzo in B-flat Minor by Frederik Chopin (Frederik Chopin Institute, 11th ed., 1950)

Figure 3: Excerpts from the subject's sight-reading, "Jazz Waltz" from *Suite Impressions* by Judith Lang Zaimont (Vivace Press, 1996)

ANGULAR DISPLACEMENT (degrees)

LEFT					
	shoulder	elbow	wrist	finger	MEAN
R1	38.18	59.19	42.14	56.07	48.895
R2	36.95	53.92	39.92	67.34	49.5325
S1	18.28	25.82	30.25	52.21	31.64
S2	23.08	32.27	34.19	51.87	35.3525
RIGHT					
	shoulder	elbow	wrist	finger	MEAN
R1	42.24	76.74	59.07	65.54	60.8975
R2	51.48	80.79	55.22	79.73	66.805
S1	23.59	22.72	37.9	64.75	37.24
S2	25.4	30.51	39.66	64.22	39.9475

Figure 4: Angular displacement for the subject in all four trials. Note that R1 and R2 represent trials of repertoire piece, while S1 and S2 denote sight-reading trials.

ANGULAR VELOCITY (degrees per second)

LEFT					
	shoulder	elbow	wrist	finger	MEAN
R1	241.85	477.03	691.66	812.24	555.695
R2	224.32	555.96	511.61	741.72	508.4025
S1	106.21	234.25	396.55	530.1	316.7775
S2	125.07	265.38	442.81	724.04	389.325
RIGHT					
	shoulder	elbow	wrist	finger	MEAN
R1	207.09	308.8	730.34	959.02	551.3125
R2	238.89	305.31	639.81	952.6	534.1525
S1	87.86	176.07	427.83	711.63	350.8475
S2	90.41	236.53	488.26	640.52	363.93

Figure 5: Angular velocity for the subject in all trials. Note that R1 and R2 represent trials of repertoire piece, while S1 and S2 denote sight-reading trials.

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