TOWARD COMPUTER-SUPPORTED PIANO LESSON FOR OPPORTUNELY ADVANCING TO CREATION STAGE

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Abstract

A piano lesson is a process where a teacher cultivates an individual pupil's creativity in piano performance, although it starts from imitation of the teacher's performance. Therefore, the teacher must act at the right moment to advance the lesson from the imitation stage to the creation stage. However, it is usually difficult to determine the best timing for switching between these two stages. To support teachers in determining this timing, this paper examines whether progress in piano lessons and the personalities of pupils can be observed through piano lesson experiments. As a result, we found that these factors can be observed by analyzing the transition of the difference between a pupil's performance and a teacher's performance with blind evaluation results of the pupil's performance by the pupil him/herself.

Key Words

piano lesson, computer support, musical creativity cultivation, individual personality

1.   Introduction

A piano lesson is a process where a teacher cultivates an individual pupil's creativity in performance. Generally, there are two stages in the course of piano lessons; an imitation stage when the teacher simply instills her/his ways of performance into the pupil and a creation stage when the pupil develops his/her own new expressions based on the instilled ways. Both stages are indispensable[1]. Ideally, the teacher opportunely decides when a certain pupil should advance to the creation stage based on careful observations of the pupil's progress and personality.

In reality, however, it is usually difficult to precisely determine the timing for switching between these two stages. We think one of the main reasons for this difficulty is the fact that both/either the teacher and/or the pupil are/is apt to be satisfied with merely imitating the teacher's way of performance. For instance, even if the pupil wants to progress to the creation stage, the teacher might continue to only instill the teacher's ways of performance. Thus, the teacher prevents the pupil from advancing to the creation stage and may inhibit the pupil's abilities. On the other hand, if a pupil is satisfied with mere imitation, it is difficult for the lesson to progress to the creation stage even if the teacher prompts the pupil to develop her/his own expressions. As a result, the lesson remains indefinitely in the imitation stage. It is assumed that young and inexperienced teachers in particular tend to fall into such practices.

Therefore, we have been exploring a method and a support system to reveal the current status of a piano lesson to make both the teacher and the pupil aware of which stage they are in, the problems in the lesson, and why the pupil cannot perform his/her own creative expressions. Toward this goal, we have examined whether the progress of the lessons and the personalities of the pupils can be precisely observed. Accordingly, we conducted piano lesson experiments with two subjects as pupils by two different teaching ways and gathered the performance data, subjective evaluation of the performances, and impressions of the lessons. This study is still an on-going project and further experiments are necessary to accurately judge the situations of the piano lessons. However, by analyzing the data gathered so far, we have obtained the capability to understand the pupils' personalities, e.g., how they were tackling the lessons and the creations of piano performance and which stages they were in. In this paper, we describe these experiments and their results and discuss how the situations of piano lessons can be grasped from the data.

This paper is organized as follows. Section 2. describes the experiments. Section 3. shows the experimental results. Section 4. discusses how the situations of piano lessons can be grasped from the results of the experiments. Section 5. mentions previous works and discuss their relationships to our study. Section 6. concludes the paper.

2.   Experiments

2.1   Experiment a procedure

A course consists of five piano lessons, and each lesson is a private lesson. One lesson is forty minutes, and a course is held for three weeks. The selected set piece is the intermediate-level "Moderato cantabile" part of "Fantaisie-Impromptu Op. 66" by F. Chopin, which is a popular,

structural and emotional piece. The teacher is C. Ooshima, who is one of the authors. About one month after a course finishes, a piano recital is held where the pupil performs the set piece three times without any instructions from the teacher. So far, we have employed two subjects (pupils A and B). They are female students at our graduate school who started playing the piano in their infancy. Pupil A, in particular, formerly applied to a music university. We let them individually practice the set piece to play without miss-touches before starting the course.

We altered the training conditions of the courses for the two pupils. The teacher aimed to instill in them her interpretation of this piece first. Therefore, the teacher gave both of them analytical instructions on the set piece. However, the teacher gave such detailed instructions to pupil A only in the first three lessons and then let pupil A perform almost freely in the remaining two lessons, while she gave detailed instructions to pupil B throughout the course.

We used a YAMAHA Silent Grand Piano C5 that outputs MIDI (Musical Instrument Digital Interface) note-on/off and pedal control messages. Therefore, we could record the performances with VCR and DAT equipment as well as by computer (SGI Indy workstation) in MIDI data. The teacher let the pupil perform the entire piece at the beginning and the end of each lesson and recorded the performances in these three ways (two more performances of the entire piece were performed in the middle of the first lesson, and they were also recorded in the same three ways). Additionally, after each piano lesson, we let the pupil write down her impressions of the instructions and of her performances. The teacher did not read them until the entire course was finished.

After a course was completed, we gathered subjective evaluations by the pupil and the teacher of the pupil's performances and the teacher's performances. That is, they listened to the recorded pupil's performances (the first and last performances of each lesson) and the teacher's performance recorded separately. The listened to each performance three times, that is, a total of 33 performances. The sequence of performances was randomly shuffled. Therefore, they could not know whose and which performance they were listening to. They graded each performance on a scale of ten (1: poor to 10: excellent) and commented on each performance.

2.2 Data analysis

First, the performance data in MIDI format is divided into the performance data of right hand and the performance data of left hand. From the performance data of each hand, we obtained the inter-onset interval (IOI), which is the interval between the onset of a note and the onset of the subsequent note for all of the notes. Then, quarter-note-level IOI was calculated by comparing the IOIs with the corrsponding note length obtained from the score. Furthermore, we also calculated quarter-note-level velocity. Each MIDI note-on message includes a velocity value. The

quarter-note-level velocity was obtained by calculating the average of the velocity values of notes included in the interval of a quarter note. In this paper, hereafter, we call quarter-note-level IOI and quarter-note-level velocity "IOI" and "velocity," respectively.

The IOIs and the velocities were normalized as follows:

$$\tilde{x}_i^{(n)} = \frac{x_i^{(n)} - \bar{x}^{(n)}}{s^{(n)}}, \qquad (1)$$

where $\tilde{x}_i^{(n)}$ is the normalized IOI or velocity of the i-th quarter note from the first of the n-th performance, $x_i^{(n)}$ is raw data of the i-th quarter note of the n-th performance, $\bar{x}^{(n)}$ is the average IOI or velocity of the n-th performance, and $s^{(n)}$ is standard deviation. In this paper, "IOI" or "velocity" means normalized IOI or velocity unless stated otherwise. A performance of a pupil and a performance of the teacher are compared as follows:

$$d^{(n)} = \sqrt{\frac{\sum_i^N (x_i^{(t)} - x_i^{(s,n)})^2}{N}}, \qquad (2)$$

where $d^{(n)}$ is the total difference between the n-th performance of the pupil and the performance of the teacher, $x_i^{(t)}$ is the normalized IOI or velocity of the i-th quarter note from the first in the performance of teacher, $x_i^{(s,n)}$ is the normalized IOI or velocity of the i-th quarter note from the first in the n-th performance of the pupil s, and N is the total number of quarter notes in the score.

We calculated $d^{(n)}$ values by using only the data of the teacher's three performaces to estimate the minimum value of $d^{(n)}$. By calculating all combinations of two of the three recorded performances of the entire set piece, the following results were obtained: $d^{(n)}_{velocity} = 0.37 \sim 0.48$, $d^{(n)}_{IOI} = 0.36 \sim 0.54$. Reproducibility of the teacher's performances was very high according to those who listened to them. Therefore, unavoidable human fluctuation caused these values, and it can be assumed that the access limit is around $d^{(n)} = 0.6$ for both velocity and IOI for the entire piece. This level can be used as an index of the end of the imitation stage.

3. Results

3.1 Subjective evaluation

Tables 1 and 2 show results of the subjective evaluation and the pupils' comments on each performance of the pupils and the teacher. In Table 1, it is evident that the first performance of the third lesson was evaluated as worst. In particular, the evaluation by pupil A became lower toward the third lesson and then higher toward the last lesson. Her comments suggest that "good performance" for her is not a performance that she played according to the teacher's instructions but a natural performance that expresses her impressions.

In Table 2, pupil B's evaluation increases toward the second lesson, decreses gradually toward the fourth lesson, and increses again toward the last lesson. Pupil B evaluated the teacher's performance as the best (9.67) and her last performance of the last lesson as the second-best (7.67). Her comments about the lowly evaluated performances are "unstimulating" and "no difference between each phrase." In these lessons, the teacher let the pupils express the difference between all of the phrases. Pupil B's comments suggest that "good performance" for her is the disciplined performance according to the teacher's instructions. However, the evaluation by the teacher was not the same as pupil B's. The teacher's comments suggest that the teacher prefers the canorous performance expressing pupil B's impressions if these performance are not modulated each phrase.

3.2 Difference between pupil and teacher

3.2.1 Global-level

Figures 1 and 2 show the velocity difference of the entire piece between the pupils' performances and the teacher's performance at each lesson. The results of subjective evaluation are also shown in Figures 1 and 2. In these figures, the x-axis corresponds to the performance, e.g., 1.1 means the first performance of the first lesson, 3.L means the last performance of the third lesson, and M.2 means the 2nd lesson in the recital held one month after the end of the course. The left y-axis corresponds to the value of velocity difference obtained by equation (2), and the right y-axis corresponds to the average grade of subjective evaluation, as shown in Tables 1 and 2. The differences by the left hand and by the right hand are separately illustrated in both figures. as "left" and "right," respectively.

In Figure 1, it is evident that the velocity difference became smaller toward the third lesson and larger toward the last lesson. Interestingly, we can see that the transition of subjective evaluation by pupil A strongly correlated to the transition of the velocity difference. Namely, the smaller the difference became, the lower the subjective evaluation became, and vice versa. On the other hand, in Figure 2, the velocity difference between pupil B and the teacher almost monotonically got smaller toward the last lesson. Furthermore, the smaller the difference became, the higher the subjective evaluation of pupil B became.

Thus, the relationship between the difference and the subjective evaluation showed opposite tendencies for pupil A and B. These results probably derive from the difference between the two pupils in their ideas of what a "good performance" is, which is mentioned in section 3.1.

3.2.2 Phrase-level

Table 3 shows the six phrases that the set piece consists of: the name of each phrase, which bars each phrase consists of, and directed dynamic marks and/or expression marks
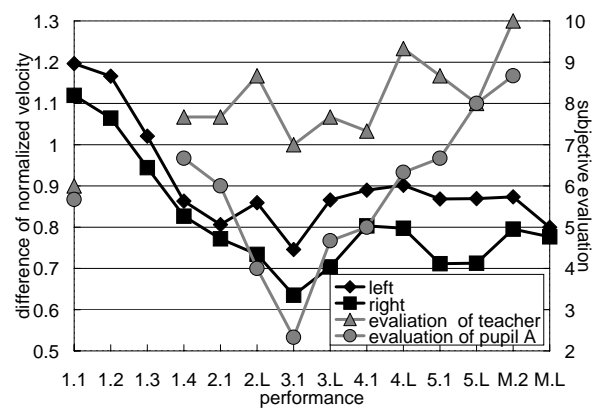

Figure 1. Transition of total difference of velocity between pupil A and teacher
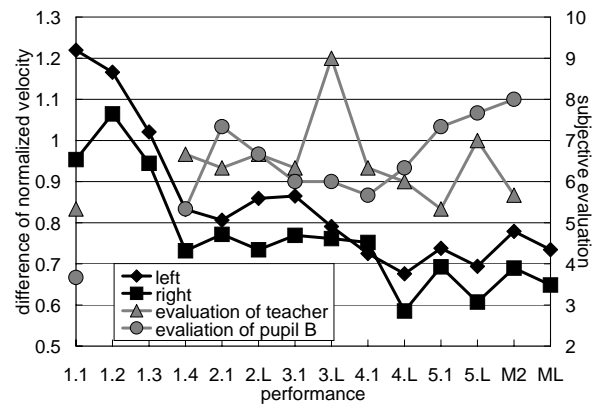

Figure 2. Transition of total difference of velocity between pupil B and teacher

for each phrase. There are three types of phrases: A, A' and B. In the Type-A phrase, fluent melody is sung to the accompaniment of a triplet in eight bars. It is difficult to play with a long time value. The Type-A' phrase is almost the same as the Type-A phrase but the last two bars are different. The Type-B phrase is more difficult in technique than the Type-A and A' phrases. There are three long steps and intermittent descent of six notes. Moreover, this phrase has forte and sforzando marks.

Figures 3-6 show the differences in velocity and IOI between the pupils and the teacher for each phrase. Figure 3 shows that pupil A achieved the lowest difference of velocity for most of the phrases at around the third lesson. On the other hand, Figure 5 shows that pupil B achieved the lowest difference of velocity for most of the phrases at around the fourth and fifth lessons. Moreover, in both Figure 3 and 5, the velocity differences of the phrases, except for the 1st A and 1st A' phrases, descend in the first lesson.

Table 1. Subjective evaluation results for pupil A's performance

lesson	performance	pupil A (average)	teacher (average)	comments of pupil A
1st	1st	5.67	6.00	Natural. I like it.
	last	6.67	7.67	No settlement, but I like a part of the piece.
2nd	1st	6.00	7.67	Not amusing. It's a disciplined performance.
	last	4.00	8.67	Safe performance, but I like the finish of each phrase.
3rd	1st	2.33	7.00	Rough.
	last	4.67	7.67	The point of performing is too clear.
4th	1st	5.00	7.33	I like this tone, but I don't like the technical skill and expression.
	last	6.33	9.33	The expression of the whole piece is not good, but I like each phrase.
5th	1st	6.67	8.67	Light. I like it.
	last	8.00	8.00	It is almost my ideal performance.

Table 2. Subjective evaluation results for pupil B's performance

lesson	performance	pupil B (average)	teacher (average)	comments of pupil B
1st	1st	3.67	5.33	Unstimulating. No modulated impression in the whole piece
	last	5.33	6.67	A little unstimulating. No difference among phrases.
2nd	1st	7.33	6.33	There are differences among phrases. Fluent.
	last	6.67	6.67	Singing. But no modulated impression in whole piece.
3rd	1st	6.00	6.33	Unstimulating. No difference among phrases.
	last	6.00	9.00	There are differences among phrases. But not fluent.
4th	1st	5.67	6.33	Unstimulating. Performance obeys score. Mechanical.
	last	6.33	6.00	Slow. Falteringly.
5th	1st	7.33	5.33	A little modulated. Some phrases are singing. Unstimulating.
	last	7.67	7.00	Fluent. There are differences among phrases. Connection is good.

Table 3. Six phrases of set piece

	name	bars	marks
1	1st A	43-50	sotto voce
2	1st A'	51-56	(no sign)
3	1st B	57-62	forte
4	2nd A'	63-70	pianissimo
5	2nd B	71-74	forte
6	3rd A'	75-82	(no sign)

Figure 4 shows that the IOI of pupil A did not fluctuate so much. However, Figure 6 shows that the IOI of pupil B fluctuated very much, in particular in phrases 1st B and 2nd B. At the final performance of pupil A one month after the course was completed, the difference values of IOI in phrase 1st B and 2nd B suddenly exceeded 1.0, while the difference values of the other phrases settled to less than 0.7.

The Type-B phrase is quite technical, and both pupils A and B commented that the Type-B phrase is difficult to perform. However, by the end of the second lesson, pupil A was able to perform the Type-B phrase smoothly, and the difference in IOI between pupil A and the teacher became the smallest. As for pupil B, although she never managed to perform the Type-B phrase smoothly, the difference in IOI between pupil B and the teacher also became the smallest

in the second lesson. In the third lesson, the teacher gave both pupils a model performance of phrase B and analytically taught them performance skills in detail. As a result, however, the differences in IOI between both pupils and the teacher became larger toward the final performance.

3.2.3 Quarter-note-level

In section 3.2.2, we examined the transition of velocity/IOI difference for each phrase through the course. As a result, we found that there are several performances that have almost the same difference values but are different when listened to. In this section, we further examine quarter-note-level transition of such phrases.

Figure 7 shows quarter-note-level velocity transition of three performances of phrase 1st A by pupil A: the first performance of the first lesson (1-1), the last performance of the fifth lesson (5-L), and the last performance of the recital one month after the end of the course (M-L). The velocity transition of the teacher's performance is also shown. In this figure, the x-axis corresponds to the sequence number of quarter notes from the first quarter note of phrase 1st A. The y-axis corresponds to normalized velocity value (not the difference in velocity shown in the previous figures). The velocity differences in performances 1-1 and M-L are almost the same: around 1.1 (see Figure 3).

While the shape of the graph of the 1-1 performance is very different from that of the teacher's performance, the
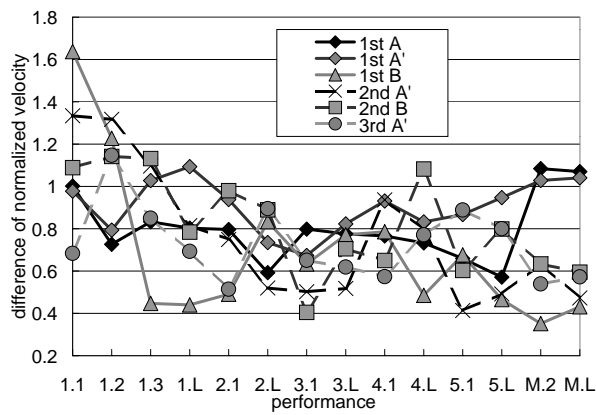
Figure 3. Transition of difference of velocity for each phrase between pupil A and teacher
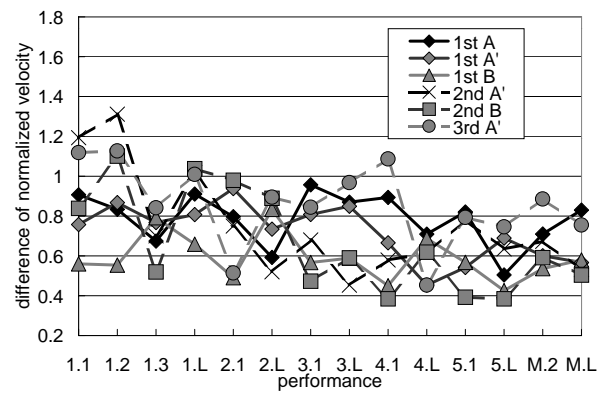

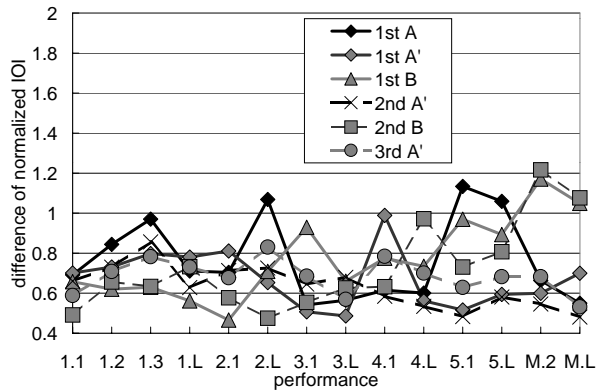Figure 5. Transition of difference of velocity for each phrase between pupil B and teacher

Figure 4. Transition of difference of IOI for each phrase between pupil A and teacher
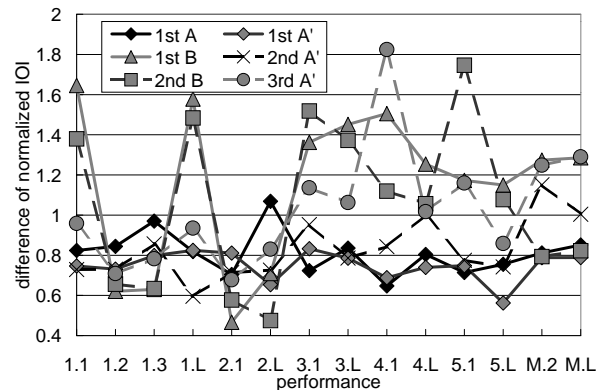

Figure 6. Transition of difference of IOI for each phrase between pupil B and teacher

shapes became very similar and the velocity difference became the smallest (0.57, Figure 3) at the 5-L performance. Then, at the M-L performance, the velocity difference returned to 1.1. However, the shape of the graph of the M-L performance is different from that of the 1-1 performance. The shape of the graph of the M-L performance is similar to that of the 5-L performance, although the range of values became narrow.

We think these results indicate that pupil A imitated the teacher's performance of phrase 1st A in all aspects at the 5th lesson. However, after that, pupil A partially abandoned the instilled way and replaced it with her own expressiveness, i.e., she basically preserved the teacher's velocity transition but she changed the range of velocity as she liked.

Figure 8 shows quarter-note-level velocity transition of four performances of phrase 2nd B by pupil A: the first performance of the first lesson (1-1), the first performance

of the third lesson (3-1), the last performance of the fourth lesson (4-L), and the last performance of the recital one month after the end of the course (M-L). Performances 1-1 and 4-L have almost the same phrase-level velocity difference value (0.9), and the performances 3-1 and M-L also have almost the same phrase-level velocity difference value (0.5, Figure 3). The fifth note of phrase 2nd B is just before a large skip. The teacher performs this note at a lower volume than the fourth and sixth notes. In the meantime, although pupil A performed it more loudly than the fourth and sixth notes in performance 1-1, she came to perform it at a lower volume than the fourth and sixth notes in performances 3-1 and 4-L. However, she came to again perform it more loudly, as in performance 1-1, in performance M-L.

This suggests that her peculiar style returned even though the imitation of the teacher's way of playing was achieved once. However, her way of playing is not so bad. Therefore, a criterion to distinguish whether an interpreta-
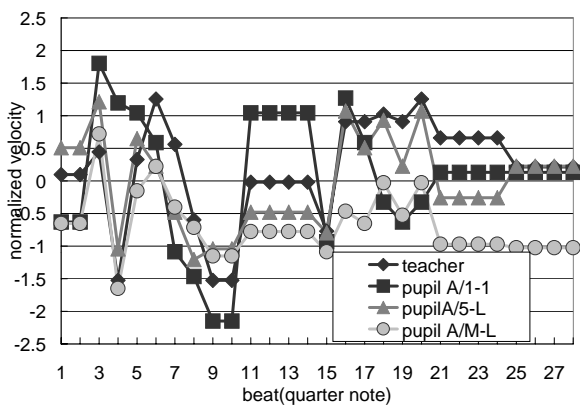
Figure 7. Velocity of each quarter note in phrase 1st A by pupil A and teacher
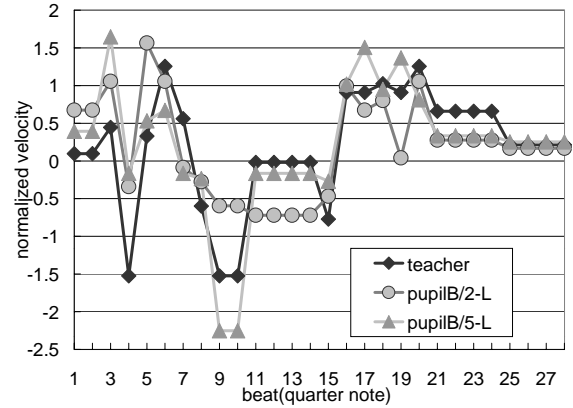

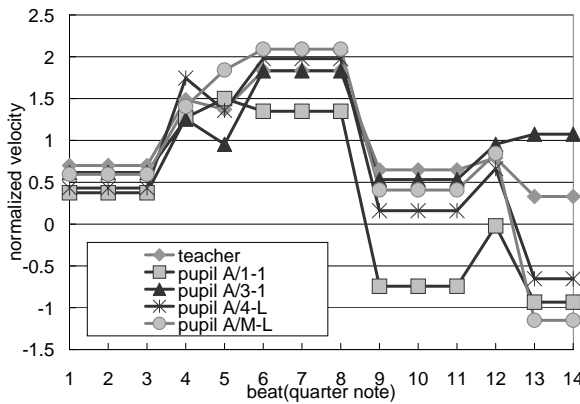Figure 9. Velocity of each quarter note in phrase 1st A by pupil B and teacher

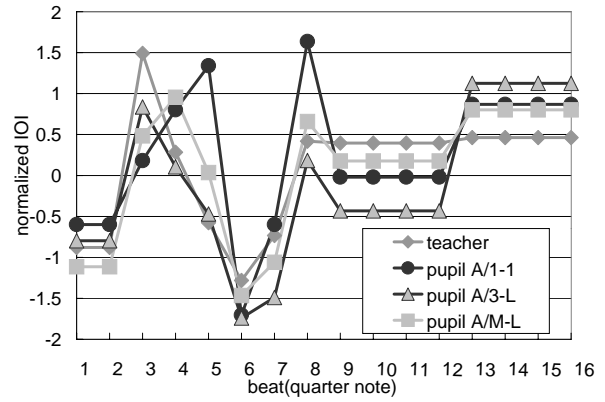Figure 8. Velocity of each quarter note in phrase 2nd B by pupil A and teacher

Figure 10. IOI of each quarter note in phrase 1st A by pupil A and teacher

tion is musically correct or not independent from the camparison between the teacher's performance and the pupil's performance is required. Currently, we lack such concrete criteria.

Figure 9 shows velocity transitions of two performances of phrase 1st A by pupil B: the last performance of the second lesson (2-L) and the last performance of the fifth lesson (5-L). The velocity transition of the teacher's performance is also shown. The velocity differences between these two performances (2-L and 5-L) and the teacher's performance are almost the same: about 0.5. However, the shapes of graphs 2-L and 5-L are quite different. Furthermore, the shape of the graph of the performance 5-L became very similar to the teacher's graph. In particular, we can see that a conventional way to perform a "breath" (a gap between successive slurs) was instilled into pupil B by the teacher's instructions. That is, the velocity of notes just before a breath must decrease (i.e., "decrescendo") toward

a breath, and then a note just after that the breath must be slightly accented. There is a breath between beat 10 and 11. Figure 9 shows that pupil B correctly performed the breath in performance 5-L, while she could not do it in performance 2-L.

Therefore, we can say that pupil B quite obediently internalized the teacher's way of performance as it is. In other words, pupil B simply imitated the teacher's way of performance.

3.3 Detailed phrasing in phrase 1st A

The teacher directed the pupils to perform one phrase like singing in one breath. However, it is difficult to perform phrases A and A', in particular, in this way. At the first lesson of pupil A, the teacher felt her performance at phrase A was loose. Figure 10 shows transition of IOI of pupil A's three performances (1-1, 3-L and M-L) and the teacher's

performance at phrase 1st A at the quarter-note level. There are four quarter notes from the fifth to the eighth beat. Those notes are difficult to perform fluently. A performer is apt to play this part discretely. When performing this part, pupil A played the fifth and the eighth beat longer than other beats in the performance 1-1. The teacher did not know this fact. At the second lesson, the teacher sang to pupil A's performance. At these four quarter notes, in particular, the teacher sang to make her performance nimble. Generally, a pianist is apt to perform such a part faster to perform one phrase like singing in one breath, and the teacher did so. Then, performances 3-L and M-L became similar to the teacher's way of performance. Finally, those performances came to be perceived as singing in one breath.

4. Discussion

4.1 Observing progress of imitation stage

In the imitation stage, it can be assumed that the level of imitation can be simply estimated as the level of similarity between the teacher's performance and the pupil's performance. The differences decreased nearly monotonically until the third lesson for pupil A and during the entire series of lessons for pupil B as shown in Figures 1 and 2, respectively. These periods correspond to the periods when the teacher was giving them detailed instructions on how to imitate the teacher's ways of perfomance. Therefore, we can conclude that the imitation stage can probably be represented as the decrement period of the diffferences in playing style.

Moreover, the difference values at the end of the imitation stage for both pupils are about $0.6 \sim 0.7$. These values are close to the estimated access limit obtained in section 2.2. Although further investigation into the value of the access limit is necessary, it may be possible to detect the end of the imitation stage when the difference value attains a certain threshold. A pupil's achievement of the access limit indicates to the teacher that he or she should move the lesson to the creation stage. However, another pupil's reaching a floor value that is larger than the access limit may show insufficient progress from the imitation stage, which indicates to the teacher that he or she should change teaching methods. In such cases, the teacher can receive suggestions on how to change teaching methods from more detailed analyses such as those shown in Figures 3-10, e.g., have the pupil concentrate on practicing only a certain phrase.

However, reckless efforts at reaching the access limit may bring bad results. For instance, in Figure 1, the teacher evaluated performance 3-1 as the worst even though the difference achieved a minimum value, while the teacher evaluated performance 2-L as the second-best. In this case, the teacher might have moved to the creation stage when the teacher was nearly satisfied with the pupil's performance, i.e., after finishing the second lesson.

4.2 Revelation of individual personality

Although the degree of achievement of imitation provides beneficial information, it is not in itself sufficient; an individual pupil's personality, e.g., the pupil's attitudes toward tackling the lesson, must also be considered. If a teacher knows a pupil's personality, the teacher can reconsider teaching methods for that pupil more suitably.

Each pupil's personality can be revealed by comparing the transition of the difference in the performance between the pupil and the teacher with the evaluation results of the pupil's performance by the pupil him/herself. In Figure 1, the smaller the difference becomes, the worse pupil A's self-evaluation becomes. This suggests that pupil A was not satisfied with only imitation and might desire to perform with her own expressions. Contrary to pupil A, in Figure 2, the smaller the difference becomes, the better pupil B's self-evaluation becomes. This suggests that pupil B concentrated on imitating the teacher's way of performance. The comments given by both pupils support these conjectures. Therefore, we can conclude that such analyses suggest certain aspects of the pupil's personality.

Such findings can be obtained only if both the transition of the objective data, i.e., the transition of difference, and the transition of the subjectve data, i.e., the transition of the evaluation results by the teacher and by the pupils, are systematically integrated. As a result of this systematic integration, profitable indications for both teachers and pupils could eventually be obtained.

5. Related Works

Recently, a large variety of piano lesson software has been developed and marketed.[1]. However, most of these software packages are designed for novice players. Many of them simply utilize a computer as a multimedia CD-ROM viewer, and the way of teaching is almost the same as simply showing an instructional video. Some of them interactively work with the pupil, but teach only basic skills, e.g., fingering. Thus, the conventional piano lesson software only focuses on the very beginning of the imitation stage. Although some of these products give a little consideration to the creation stage, they do not suggest how to creatively perform, what the personalities of the pupils are, when a certain pupil should move to the creation stage, and so on.

Musical creativity has mainly been discussed in the research domain of music perception. Many efforts have investigated how musical creation is achieved (e.g., [2] and [3]), and several models of expressiveness have been proposed (e.g., [4]), mainly based on analyses of creation by professional pianists. These studies have suggested very interesting information on musical creativity. However, they do not suggest how we can achieve our own creative musical potential nor how a teacher can encourage pupils to

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[1]Refer to http://www.unm.edu/∼loritaf/pnosoftr.html

achieve their own creative musical potential.

On the other hand, in the research domain of musical performance systems, attempts have been made to extract ways of professional performers' expressiveness by applying machine learning technology and to implement the extracted ways on a computer [5]. Moreover, to evaluate the quality of generated performance, an evaluation system has been developed that compares the generated performance with normative performance obtained from several human performers [6]. These systems and methods are partially applicable for our purpose. However, while the goal of musical performance systems is to simply to imitate a human (i.e., a teacher) as perfectly as possible, the fundamental goal of a human's piano lesson is to let a pupil achieve her/his own creative expression. Therefore, for example, a music lesson support system must suggest when the teacher should stop simply imparting his or her knowledge to the pupil. Conventional systems do not provide such information.

6. Conclusion

Generally speaking, there are two stages, i.e., the imitation stage and the creation stage, in the course of piano lessons; however, it is usually difficult to precisely determine the timing for switching between these two stages for inexperienced teachers. Therefore, we have been exploring a method and a support system to reveal the situations of piano lessons. Toward this goal, we have examined whether the progress of the lessons and the personalities of the pupils can be precisely understood. Accordingly, we have conducted piano lesson experiments with two subjects as pupils by two different teaching methods and have gathered performance data, subjective evaluations of performances, and impressions of the lessons.

From the results of analyses, the imitation stage can be represented as the decrement period of the diffferences between the pupil's performance and that of the teacher. Furthermore, we achieved the ability to detect the end of the imitation stage when the difference value attains a certain threshold as well as when the teacher's evaluation of the pupil's performance becomes relatively high. Additionally, each pupil's personality, e.g., the pupil's attitude toward tackling the lessons, could also be observed by comparing the transition of difference in velocity and IOI data with the results of a subjective evaluation by the pupil. These results suggest the best timing for progressing from the imitaion stage to the creation stage and/or reconsider teaching methods.

We have examined the progress of the lessons with the two students and could obtain some interesting findings and suggestions so far. We would like to conduct further experiments with many other students and teachers to obtain more general results. On the other hand, we would like to continue the experiments with the same two pupils using different set pieces, different teaching methods and so on, to investigate the progress of the lessons, their personalities and so on in more detail.

We measured only velocity data and IOI data so far. However, they may not be enough to understand, evaluate, and compare the performances of a teacher and pupils: e.g., even if the velocity data of two notes are the same, their sounds are usually different. We intend to measure other factors that affect sound and performance; after touch, pedal control, etc. Currently, we employed the model on the progress of piano lessons where a student advances to the creation stage from the imitation stage straight. However, we think that our model may be too simple and some other more complicated but practical models, e.g., a spiral model where a student turns these two stages alternately, may have to be employed. Obtaining criteria to distinguish whether an interpretation is musically correct might be another challenging issue. However, finding such criteria is very difficult and may actually be impossible. We believe that creativity essentially belongs to humans, not machines or systems, and that only people can evaluate creativity. Therefore, we think the combination and cooperation of a human's subjective evaluation ability and a computer's objective evaluation ability would provide more benefit than using either of them alone.

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