Family Ensemble: A Collaborative Musical Edutainment System for Children and Parents

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ABSTRACT
In this paper we propose a collaborative musical edutainment system named “Family Ensemble” (FE). FE allows a parent and his/her child to readily enjoy ensembles together at home, in this case, a piano duo, even if the parent has little or no experience in playing a musical instrument. FE makes it easier for the parent to correctly perform given melodies along with his/her child’s performance, using a score-tracking algorithm that can cope with the particular errors commonly made by beginners, i.e., children. By supporting the parent, FE prompts the child to practice the musical instrument more willingly. In experiments, we confirmed that FE can facilitate the playing of duos by pre-instrumental performers and beginners. Furthermore, we found, during a joint practice using FE, that some subjects discussed musical ideas that they could not have talked about without the system. Thus, not only does FE encourage children to willingly practice the piano but it also allows even pre-instrumental performers and beginners to aim for richer musical expression and a deeper understanding and appreciation of music.

Categories and Subject Descriptors
H.5.5. [Sound and Music Computing]. K.3.1. [Computer Uses in Education].

General Terms
Experimentation.

Keywords
music edutainment, support system, score tracking, beginner, piano duo.

1. INTRODUCTION
In this paper, we propose a collaborative musical edutainment system named “Family Ensemble” (FE). FE allows a parent and his/her child to readily enjoy ensembles together at home, in this case, a piano duo, even if the parent has little or no experience in playing a musical instrument.

Some families have enjoyed playing music in the home since the eighteenth century. After dinner, sisters might play a Mozart symphony as a piano duo, or a father might play the jazz music on a violin with his son’s accompaniment on the piano. This custom has played an important role not only in communication among family members but also in music education. Today, despite the ready availability of recorded music, there are still many families who want to play music at home. Usually, however, we see only a few families performing ensembles at home.

Recently, in piano playing education, the efficacy of duo play in the learning process has come to be widely recognized [1][10][12]. Even if a pupil who has just started to practice the piano one week ago plays a piece that consists only of “Do” notes, it is desired that a teacher accompanies him/her with various chords on the piano.

It has often been reported that children who have played duos come to practice more enthusiastically and to perform more musically [13]. However, most children can play duos only in school, since most of their parents cannot play the piano. Few marketed scores of piano duos are arranged for two beginners. This fact also shows the difficulty in playing a duo by beginners. Recently, there are various “minus-one” software applications in which all parts except for the pupil’s part are recorded [4][10]. Professors of music, however, comment that minus-one software prevents the pupils from acquiring the skill of cooperative performance that is essential for ensembles [13].

On the other hand, the parents of children who are learning to play a musical instrument are often eager to play music with them. Recently, music schools for adults and software for learning to play particular musical instruments have become popular, at least in Japan. These schools and/or software usually focus only on enabling the learners to perform their favorite pieces. However, if they want to perform various works with other people, e.g., their children, they must eventually start from the basics. The need to undertake difficult training for many years makes most parents give up the dream of being able to play duos with their children.

Accordingly, in this paper, we propose “Family Ensemble,” which supports ensemble performances by a parent who has little or no experience in playing the musical instrument and his/her child who is a beginner in playing the instrument. Though any type of
performance interface can be applied to FE, we employed a piano keyboard to conduct our experiments. We designed FE for performing “reproduction-type music” like classical music, in which musicians should correctly perform the notes described in a given score (in contrast to jazz, in which musicians are expected to improvise freely). FE tracks the child’s performance in real-time. By referring to the tracking results, FE decides which notes the parent should perform at each point. Even if the parent strikes the wrong keys on the keyboard, FE replaces the incorrect notes with the correct ones [14].

Thus, FE allows any parents to immediately play a duo with her/his child, following the child’s performance. FE will bring about a new cooperative learning method in music education at home for parents and children. We would like to emphasize that FE directly supports the parent, not the child. We believe that a child who is studying the piano should use a normal instrument and that direct support would detract from the learning process. We also think that the following are important aspects for constructing a system as music edutainment: 1) Interaction with not a computer but a person, 2) Knowing incorrect elements, e.g., incorrect pitches and no sense of rhythm, through listening to one’s performance, and 3) Room for growth, i.e., the system should not intervene in musical expression. A system that includes these aspects gives even pre-instrumental performers the enjoyment of musical performance, eagerness to practice, and the knowledge that they can perform richer music.

Technologies for automatically tracking human musical performances have been studied mainly in terms of automatic accompaniment systems. Dannenberg [5] developed an algorithm for tracking a score based on pitch-sequence data by applying a DP-matching method. Wercoe [19] developed a score-tracking method by referring not only to the pitch-sequence but also to the sounded time of each note. In addition, a human cognition model for estimating musical performance in an ensemble was taken into account. Studies of an automatic jam session system attempt to follow the emotive transition of human performer(s) [7]. Although the score-tracking function of FE is an extension of Dannenberg’s algorithm, as described later, all of these preceding studies aim at enabling ensemble play by an advanced human performer and a machine. FE, in contrast, aims at enabling ensemble play by human pairs with a little and no experience in playing the musical instruments.

In regard to the study of interactive musical systems, the Continuator [16] is a system that supports a user in learning musical styles. When the user plays a musical sequence of any kind (i.e., a phrase), the Continuator, in turn, generates a musical phrase in response to the user’s phrase based on a Markov model of the musical phrase. The experimental results showed that they played with the system in a self-motivated way. The Jum-O-Drum [2] is a system that allows up to six players to practice collaborative musical improvisation. pianoFORTE [17] is a system that records and displays several aspects of a user’s performance. This system aims to have the teacher discuss with a student about the distinction between the art of playing piano and the technique of playing the correct notes. DrumSteps [11] is a dynamic graphical interface that enables children to create, manipulate, edit and save original pieces of percussion music. Toy Symphony [9] is an international music performance and education project that allows children to play alongside some of the world’s most accomplished musicians, and to learn by doing. Several interesting tools or instruments have been developed in this project. For example, Music Toys are specially developed musical instruments that allow everybody to easily enjoy musical performances. Hyperscore [6] is a tool that enables children to ‘compose-by-drawing’. It is designed to introduce children to musical composition and creativity in an intuitive and dynamic way. FE provides no special tools to the learners while these systems provide special tools to them. FE indirectly prompts the children’s learning with self-motivation as well as communication with his/her parents.

In the next section, we will investigate features of the beginners’ mistakes in performances and describe the FE system design based on the investigation results. Then, we will illustrate our experiments and discuss the effects of FE. Additionally, we discuss a system for music edutainment. In the final section, we will conclude this paper and outline future work.

2. FEATURES OF BEGINNERS’ PERFORMANCES
FE has to be adapted to even beginners’ performances. We thus examine the kinds of errors that beginners are apt to make.

1. **extra**: An extra note that does not match any notes in the score is performed.
2. **wrong**: Though a performed note matches a note in the score, its pitch is incorrect.

<table>
<thead>
<tr>
<th>Place</th>
<th>A</th>
<th>B</th>
<th>Sum</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>extra</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>wrong</td>
<td>0</td>
<td>37</td>
<td>37</td>
<td>61</td>
</tr>
<tr>
<td>missing</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1st beat</td>
<td>315</td>
<td>144</td>
<td>459</td>
<td>75.4</td>
</tr>
<tr>
<td>2nd downbeat</td>
<td>17</td>
<td>2</td>
<td>19</td>
<td>3.1</td>
</tr>
<tr>
<td>Last beat</td>
<td>0</td>
<td>6</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>Start of phrase</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>0.8</td>
</tr>
<tr>
<td>A hesitation</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>1.3</td>
</tr>
<tr>
<td>1st beat pre-bar</td>
<td>26</td>
<td>25</td>
<td>51</td>
<td>8.4</td>
</tr>
<tr>
<td>Last beat pre-bar</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>0.8</td>
</tr>
<tr>
<td>Start of piece</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>1.7</td>
</tr>
<tr>
<td>Start of column</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td>Sum</td>
<td>381</td>
<td>224</td>
<td>605</td>
<td>100.0</td>
</tr>
</tbody>
</table>

2.1 Outline of Experiments
We conducted experiments with two children who have been studying the piano. Subject-A had studied the piano for four years. She is a fourth year student of an elementary school. Subject-B had studied the piano for one year. She is a nursery school toddler and a sister of Subject-A. Subject-A was asked to perform seventeen pieces that she had never performed before in four thirty-minute experiments. Subject-B was asked to perform thirteen pieces that she had never performed before in four thirty-minute experiments. Their pieces include piano pieces for four hands. They were asked to perform pieces from one to five times according to the level of difficulty. We recorded the sounds and utterances of these experiments on a DVD-RAM disk.

2.2 Results
Ordinary score tracking systems (e.g., [5][8][15]) deal with three types of performance errors as defined by Bloch & Dannenberg [3], assuming that the target users are experienced performers and that their performances closely match the scores.

1. **extra**: An extra note that does not match any notes in the score is performed.
2. **wrong**: Though a performed note matches a note in the score, its pitch is incorrect.

Table 1. Frequency of errors

<table>
<thead>
<tr>
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<td>Sum</td>
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<td>605</td>
<td>100.0</td>
</tr>
</tbody>
</table>
3. **missing**: A note in the score is not performed.

While beginners also make these three errors, it is necessary to add a fourth type:

4. **replaying**: An extra note sequence that matches a part of the score is performed. In other words, an undirected refrain is performed.

Table 1 shows the frequency of errors, i.e., extra, wrong, missing, and replaying. As for replaying, in addition, the places where the subject restarted and the frequency of each restarted place are shown. “1st beat” means that the subject restarted at the 1st beat of the same bar as where the subject stopped her performance. “2nd downbeat” means the 2nd downbeat, i.e., the 3rd beat of a quadruple measure or the 2nd beat of a binary measure. “Last beat” means the last beat, i.e., the 4th beat of a quadruple measure. “Start of phrase” means the start of the slur mark. “Alternation” means where a performer needs to alternate right hand with left hand in one phrase. “column” means a group of bars forming a line on a printed score. “pre-bar” means that the subject restarted at the bar preceding where the subject stopped performing. The three categories of “1st beat,” “2nd downbeat” and “Last beat” do not include “Start of phrase,” “Start of piece,” “Start of column” and “Alternation.”

Subject-A made 381 mistakes and Subject-B made 224 mistakes in total. Surprisingly, the cases of replaying were 377 times in 381 errors in Subject-A performances, and 181 times in 224 errors in Subject-B. Moreover, “1st beat” accounted for about 75% of all errors. Thus, we need to consider all four types of error in order to construct a supporting system for beginners’ ensemble playing.

3. **SYSTEM DESIGN OF Family Ensemble**

3.1 Setup of Family Ensemble

We developed FE as a system to support the playing of duos on the piano. The system was implemented by Visual C++ and runs on Windows XP or 2000. We call the part of the child “Primo,” that is, the part that performs the upper register of a duo, and the part of the parent “Secondo,” that is, the part that performs the lower register. FE supports Secondo by detecting where Primo is playing in the score in real time.

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1 The extra note sequence may include errors of the other three types.

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Figure 1 shows the setup of FE. Primo’s performance is output as MIDI (Musical Instrument Digital Interface) data and directly input to a sound generator as the notes are played. At the same time, Primo’s performance data are input to the score-tracking module that determines Primo’s current position in the score. The obtained current position data are input to the note-number-acquisition module. This module compares Primo’s current position with Secondo’s score. As a result, the MIDI note number(s) that Secondo should play at that moment is (are) acquired. The acquired MIDI note numbers are input to the note-number-replacement module. This module replaces the MIDI note number(s) that Secondo played with the acquired correct MIDI note number(s), while the other characteristics of the performed note(s), i.e., loudness and length of sound, are preserved as they were performed. Consequently, by using any keys, Secondo can perform the correct notes, with his/her own expression alongside Primo’s performance.

If Secondo stops playing for a moment while Primo keeps on performing, Secondo can immediately resume the performance from the correct place in the score. On the other hand, if Primo suddenly stops playing while Secondo keeps on performing, Secondo cannot proceed beyond the point where Primo stopped. When Primo resumes the performance, Secondo can resume the performance, too. Even if Primo returned several notes back when Primo resumes to play, Secondo can quickly catch up with it by the score-tracking function that is described in 3.2.

3.2 Score-tracking Module for Beginners’ Performances

We extended Dannenberg’s score-tracking algorithm [5], which is based on the DP-matching method, to cope with the fourth type of error, i.e., replaying. Similar to Dannenberg’s algorithm, our algorithm deals only with pitch data. Let the number of notes in Primo’s score be $N$, where a chord is regarded as a note and is represented by its highest note, and let the “performance time” be $t_j$ where $j$ is the number of notes performed by Primo. Now, assuming that the current position at the performance time $t_{j-1}$ was decided at the note $S_j (1 \leq j \leq N)$ in the score, Primo performed a note $P_j$ at performance time $t_j$. In this case, our score-tracking module determines the correspondence between the note in the score and the performed note $P_j$ based on the following algorithm:

1. First, $Pitch(P_j)$, i.e., the pitch of the performed note $P_j$, is compared with $Pitch(S_k)$ of each note in the score $S_k (1 \leq k \leq N)$ . Then, the weight of each note $S_k$ at the performance time $t_j$, i.e., $W(S_k, t_j)$, is calculated as follows:

   (a) if $Pitch(S_k) = Pitch(P_j)$
   
   then $W(S_k, t_j) := W(S_{k-1}, t_j) + 1$.

   (b) else $W(S_k, t_j) := W(S_{k-1}, t_j) - 1$.

   where if $W(S_{k-1}, t_j) - 1 < 0$ then $W(S_k, t_j) := 0$

2. If $W(S_{k+1}, t_j) \neq W(S_k, t_j) + 1$, some error is detected. In this case the following correction algorithm is applied.

   (a) To correct a replaying error, let $W(S_k, t_j) := W(S_{k-1}, t_j) - m$, where $S_k$ is the point in the score to which the beginner is likely

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2 The MIDI note number represents the pitch of the note.
Figure 2. Score-tracking algorithm

to return when he/she stops playing, as enumerated in the previous subsection. At present, m is empirically set to 2.
(b) To correct extra, wrong and missing errors, let $W(S_i, t_j) := W(S_{i-1}, t_j)$, where $S_i$ is all notes from $S_n$ to $S_{i+r}$. At present, $r$ is empirically set to 2.

3. Finally, the score-tracking module decides a note $S_l$ whose weight $W(S_l, t_j)$ is the largest as the current position at performance time $t_j$. If there are multiple notes whose weights are the largest, the module chooses one note as follows:
(a) If $W(S_{i+1}, t_j)$ is the largest then $S_{i+1}$ is decided upon as the current position.
(b) If $W(S_i, t_j)$ is not the largest then
i. a note $S_h$ whose weight is the largest and that is the nearest to the note $S_l$ is decided upon as the current position.
ii. If two notes $S_{i+d}$ and $S_{i+d}$ have the same largest weight and are both nearest to the note $S_n$, $S_{i+d}$ is decided upon as the current position.

Figure 2 illustrates our score-tracking algorithm.

This algorithm achieves robust score-tracking even for the performances by the children with a little musical experience in virtue of the function to cope with the “replaying” type error as well as the three ordinary types of errors. Figure 3 shows situations of score-tracking. (a) shows the result in the case in which the system corrects a replaying error. (b) shows the result in the case in which the system does not correct a replaying error. Column corresponds to notes described in the score. Row corresponds to notes performed by Primo, $P_i$. The hatched part of the performed notes shows where Primo replayed. Consequently, in this case, Primo replayed “sol, la, sol, mi…” although she should have played “mi, sol, sol, sol…” Furthermore, cells that include outline characters show the estimated current position that the score-tracking module decided upon. Cells surrounded by a black border show the actual correct notes that Primo is playing at each point.

In figure (a), we can see that the notes “sol” and “do” have weight “11” at the start of replaying. We had appointed these two notes to correspond with the start of bars beforehand. Accordingly, the system could follow Primo’s performance after mistakes of only three notes. On the other hand, in figure (b), the system mistook thirteen notes before following Primo’s performance correctly. Thus, we can see that our score-tracking algorithm, which adds to correct replaying errors, is practical.

As for usual musical pieces, this algorithm works enough robustly. In some extreme cases, however, it might not be able to be restored from an error. For example, if one makes a mistake during the first eight bars of “One note samba” that consist of only notes of an identical pitch (F), it is impossible to find the correct position. Time values of notes should be taken into account to track such a piece. It is also difficult to track a piece that consists of only an identical motif, e.g., a simple repeat of “do, re, mi, re” over and over. As for the processing time of this algorithm, although it scans over the entire piece each time, pieces that beginners perform are usually short and simple. Practically, therefore, the total processing time can be ignored.
Table 2. Results of the number of performance in the fifteen-minute joint practices without and with FE

<table>
<thead>
<tr>
<th>Piece</th>
<th>Without FE</th>
<th>With FE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duo</td>
<td>Sub</td>
</tr>
<tr>
<td>Pair-A</td>
<td>Prelude</td>
<td>0</td>
</tr>
<tr>
<td>Pair-B</td>
<td>Prelude</td>
<td>5</td>
</tr>
<tr>
<td>Pair-C</td>
<td>Takibi</td>
<td>2</td>
</tr>
<tr>
<td>Pair-D</td>
<td>Takibi</td>
<td>0</td>
</tr>
<tr>
<td>Pair-E</td>
<td>Prelude</td>
<td>0</td>
</tr>
</tbody>
</table>

*The Secondo played a part of right hand.

**The Secondo played only five notes.

4. TRIAL EXPERIMENTS OF FAMILY ENSEMBLES

4.1 Methods

4.1.1 Subjects
We employed five pairs of subjects as follows:

[Pair-A] Primo was a female junior high school student who had studied piano for eight years (intermediate). Secondo was her father who had never played the piano and it was hard for him to read the scores (pre-instrumental performer).

[Pair-B] Primo was a female elementary school student who had played piano for four years (beginner). Secondo was her mother, who had studied the electronic organ for two years (extreme beginner).

[Pair-C] Primo was a nursery school child, the other daughter of the Secondo of Pair-B. She had been studying piano for one year (extreme beginner).

[Pair-D] Primo was a male student at our institute who had studied the electronic organ for eight years (intermediate). Secondo was a male student at the same institute who had never played the piano and it was hard for him to read the scores (pre-instrumental performer).

[Pair-E] Primo was the same as Pair-D. Secondo was another male student at the same institute who had never played the piano and it was hard for him to read the scores (pre-instrumental performer).

4.1.2 Set pieces

The ranking of technical ease for Primo is “Takibi,” “Prelude” and “Waltz.” On the other hand, the ranking for Secondo is “Prelude,” “Takibi” and “Waltz” without FE, as well as “Waltz,” “Takibi” and “Prelude” with FE. The ranking of technical ease with FE is decided by the rhythmical difficulty of the score.

Hence, we asked Pair-A, the Primo who was the most experienced among the five pairs, to perform all three pieces with FE, and to perform “Prelude” without FE. According to each Primo’s ability and preparation period, Pair-B and E tried “Prelude” and “Takibi” with FE, and tried “Prelude” without FE. Pair-C and D tried “Takibi” with and without FE.

Additional to using FE, we asked the subject who played Primo for Pair-D and E to try to use minus-one software that cuts out Primo’s part from a duo. We prepared minus-one software for two set pieces, “Takibi” and “Prelude.” The set piece, “Takibi” was prepared in three tempo patterns, i.e., 44 (slow), 60 (medium), and 72 (fast) quarter notes are beat per minute. Another set piece “Prelude” was also prepared in three tempo patterns, i.e., 72 (slow), 88 (medium), and 104 (fast) quarter notes are beat per minute.

4.1.3 Procedure of Experiments
We asked each Primo to practice the given set pieces beforehand, until they could perform them with few mistakes. Then, we asked each pair to jointly practice the duos, both with and without the use of FE. Each joint session was fifteen minutes long.

[Record-1] The parent sat by his/her child who was practicing alone for five minutes in Pair-A, B and C.

[Record-2] Pair-A, B and E had a joint practice to perform “Prelude,” and Pair-C and D had a joint practice to perform “Takibi” without FE for fifteen minutes.

[Explanation] We explained how to use the system and let the Secondo try it, using a short trial piece.

[Record-3] Pair-A, B and E had a joint practice to perform “Prelude,” and Pair-C and D had a joint practice to perform “Takibi” with FE for fifteen minutes.

[Record-4] Pair-A, B and E had a joint practice to perform “Takibi” with FE for ten minutes.

[Record-5] Pair-A had a joint practice to perform “Waltz” with FE for ten minutes.

[Record-6] The Primo of Pair-D and E tried to perform “Takibi” and “Prelude” with minus-one software in the three kinds of tempo for each piece.

Our experiments were conducted on an acoustic grand piano that can output MIDI data in a soundproof room in the second author’s institute. The piano was connected to a personal computer on which the FE system ran and to a sound generator.

In the joint practices with FE, the Secondo was allowed to use any keys below C3, i.e., “Do” on the observer’s left, which Primo did not need to use for playing the set pieces. Moreover, Secondo used a special score. Since FE replaces the pitch of the performed notes with the correct pitch, regardless of which keys Secondo plays, Secondo does not need to read the actual notes on the score. Therefore, we gave Secondo a so-called “rhythm score” in which pitch data was omitted. In this score, a chord is represented by piled note symbols, in numbers which correspond to the number of notes in the chord. The Secondo can play a chord by hitting multiple keys at once. By hitting multiple keys to perform a chord, the Secondo can separately control the volume and length and each constituent note in the chord.

4.1.4 Questionnaires
After recording the performances with and without FE, the subjects were asked to answer the following questions.

[To both Primo and Secondo]
Question-1: Is it difficult for the Secondo to perform a set piece without FE? ("1" is very easy to "5" is very difficult)

Question-2: Why do you think so? (Optional)

Question-3: Is it difficult for the Secondo to perform set pieces with FE? ("1" is very difficult to "5" is very easy)

Question-4: Why do you think so? (Optional)

Question-5: How do you feel about Secondo being able to perform with only one finger? (Optional)

Question-6: Do you want to play a duo with FE again? ("Yes," "Marginal," and "No")

Question-7: Why do you think so? (Optional)

Question-8: Who do you want to play a duo with?

Question-9: Please comment on some expected improvements, etc. (Optional)

[About minus-one software to the Primo of Pair-D and E]

Question-10: Could you perform the set pieces with the correct melody and rhythm?

Question-11: Could you express agogics and fermata, i.e., subtle changes in tempo?

Question-12: Could you express dynamics?

(In the case of the Slow, Middle, and Fast tempo, "1" is "could do it" to "3" is "could not do it.""

4.2 Results

Table 2 shows the number of subjects playing duo and solo in fifteen minutes in the joint practice without and with FE. We counted the frequency of a pair or one of the performers playing from start to end even if there were many errors. Consequently, even if the Secondo could perform only five notes in a duo, we considered it one duo as shown in Pair-B and C. Table 3 shows the results of Question-1, 3, 6, 8 as well as Table 4 shows the results of Question-11, 12, 13, i.e., concerning to using minus-one software.

We can see that none of the pairs could complete the duo in the joint practice without FE. On the other hand, with FE they immediately performed the duo more than ten times within the fifteen-minute session (see Table 2). In the joint practices of Pair-A, B, D, E without FE, the Primo was busily occupied telling the Secondo which key(s) to hit. According to answers of Question-2, especially the Secondos of Pair-A, D, and E did not know how to read notes or the correct position corresponding to each note on the score. Hence, the results of Question-1 on Table 3 show that most Primos and Secondos thought it was very difficult to play a duo without FE, i.e., answer of “5.”

Moreover, we should notice the increase in the number of solo practices by the Primos in joint practice with FE (see Table 2). According to the answers of Question-9, the Secondo of Pair-D wrote that FE prompted him to practice playing the musical instrument. Primos’ performances became poorer than those of Secondos supported by FE, and so Primos wanted to recover their domination by practice. This result suggests that FE can prompt children who are studying the piano to practice more eagerly.

According to the answer of Question-5, The Primos of all pairs did not feel envious of the FE support for their partner. However, in the case of joint practice with FE, the performance became imperfect due to the Primo’s mistakes in reproducing correct pitches. Therefore, the Primo of Pair-A felt frustrated that she could not blame her father when the performance was not perfect (answer for Question-5).

According to the answers of Question-4 and 7, the Secondos of Pair-D and E answered it was very wonderful that they could perform from the start to the end of the pieces. According to the answers of Question-6, all subjects want to use FE again. The subjects of Pair-D and E wanted to use FE with their friends as a form of entertainment (see the answer of Question-8).

On the other hand, the Secondo of Pair-B and C, who has a little experience in playing the organ, answered that she hopes to be able to play the piano more naturally. In the session of pair-B without FE, she tried to perform only the right-hand-part. The rate of correct notes that she played became 76.7% of all right-part notes on the score in fifteen minutes. According to the answer of Question-9, she proposed a way of support such that the Secondo can perform the right-hand-part practically with the left-hand-part supported by FE.

The subject who played the Primo of Pair-D and E tried to use minus-one software in “Takibi” and “Prelude.” Table 4 shows that he could almost perform it in the medium tempo. However, he answered that he could not perform with subtle changes in tempo and dynamics, i.e., musicality in any tempo (see answers for Question-11 and 12).

4.3 Discussion

The results of the experiments clearly show that FE allows even extreme beginner to immediately play duo performances. There are differences in parent-child relations between the cases of joint practicing with FE and without FE. These changes prompt the children to practice more enthusiastically. Moreover, it is suggested that FE has a desirable effect on their musicality.

4.3.1 Motivate children to practice more

In the joint practice without FE, the Primo taught the Secondo how to read notes on the score, what position of keys the Secondo should touch, and so on, in Pair-A, B, D, and E. We can see that the Primos are very active in teaching their partners. However, they could not perform a set piece once. In Pair-C, the Primo is a nursery school child as well as an extreme beginner. Therefore, successfully performing her part is all she can do. As a result, she is displeased that her mother, who has a little experience, generated wrong pitches.

In the joint practice with FE, the following dialogue took place between the child and her father of Pair-A.

(After the first duo)
Child: machigaeta=
Father: "I made mistakes.
Father: =damedane::=
(That’s too bad.)
Child: =mukatuku
(Darn it!)
Father: ja, mou 1 kai ikimasyone
(Well, shall we play the piano one more time?)
Father & Child: Play duo
(Made a bad start, and stopped immediately)
Father: omae mazu rensyu sei!
(Do your practice firstly!)
Child: un rensyu suruwa
(I see. I am going to practice.)
Child: Play solo
Child: yosya ikou
(OK! Let’s go!)
Father: eeka?
(Are you ready?)
Child: otosan to hikuto yariniku mono
(It is tricky to play with dad.)
Father: nandeyanen
(Why?)
Child: dakara motyotto sa
(yeah yeah yeah)
Father: =un un
(yeah yeah)
Child: dakara motyotto sa
(Yes, a bit more like this.)
Father: un motto ko nobasete iuno?
(You mean I should sustain the sounds, right?)
Child: =so
(Right!)
Father & Child: Play duo
By using FE, a pre-instrumental parent and child with a little experience are on almost even ground in reproducing correct pitches. Consequently, if the child cannot perform the piece perfectly through lack of practice, the parent can achieve the rank of the child. In this dialogue, an utterance of the child, “otosan to hikuto yariniku mono (It is tricky to play with dad.)” shows that she is impatient with her incomplete performance. After all experiments, her comment in this utterance relates that the performance not being perfect is due to the Primo part, in reproducing correct pitches (section 4.2.2). Therefore, she is frustrated that she could not blame her father when the performance is not perfect. However, the children’s impatience may promote more enthusiastic practice. Actually, the results of the experiments show that in the joint practice using FE the Primos practiced by themselves (Table 2).

4.3.2 Construct their performance more musically
The fact that the parents could easily play their part correctly with the help of FE also had a desirable effect on another aspect of musicality. The following dialogue took place between Pair-A in the joint practice with FE.

Child: ano ko tan tan tte hikuto to shi jireru wakeyo=
(Well, your key-touch is like “tan tan tan,” This way of touch indicates disconnected tapping sounds.)
Father: =un un un
(yeah yeah)
Child: dakara motyotto sa
(Yes, a bit more like this.)
Father: She played the Secondo part
Child: hen motto ko nobasete iuno? =
(You mean I should sustain the sounds, right?)
Child: =so
(Right!)
In other words, the child wanted her father to play his part more legato. This kind of conversation on musical expression was never found in the joint practice of any of the pairs without FE; the Secondo could consider nothing other than performing his/her part.

Moreover, though the father of Pair-A was an extreme beginner, he was able to point out that their timing was off at dotted notes;

Child: o dekitayan=
(Oh! We completed it!)
Father: =a koko aitaine
(Well, I want the timing in this part to be right.)
Child: ta-n ta tan
(ta-n ta tan)
Father: Playing the dotted notes
Father & Child: Play solo
Child: ta-n ta tan
(ta-n ta tan)
Father: so so ta-n ta tan un kokodake rensyusuru
(Well, I want the timing in this part.)

Primarily, ensemble practice should be a time when the players construct their own performance by conveying their musical ideas and performance plans to each other. Without FE, such discussions of musicality could not be achieved because of the knowledge gap between the Primo and Secondo (e.g., the Secondo cannot even read a normal score) and because of the Secondo’s lack of technical ability. However, FE can fill this gap, that is, the parent and the child become almost technically equal with the support of FE. Thereby, they become able to practice jointly toward a richer musical performance.

4.3.3 Edutainment
Tollinger [18] criticizes music education software based on the following four aspects: a) educational value, b) pedagogical validity, c) user-friendliness, and d) developmental consideration of the audience/user. In the case of FE, the results of experiments show the “user-friendliness” of FE (section 4.2.5). The subjects answer that they want to use FE more even after experiments using each way. The fact that the subjects started to practice more eagerly and practice toward a richer musical performance shows the “educational value” and “pedagogical validity” of FE. Moreover, the children and their parents can learn the children’s development level objectively by listening to their performance while playing. Concerning the development of reproducing correct pitches, for example, if the child mistakes some notes, he/she can listen to poor harmonies. On the other hand, concerning musicality, the expression in playing can be conveyed to both partners. Consequently, the children and the parents can learn the development of each other’s musicality. We think these good effectiveness are brought by three important aspects for constructing system as music edutainment that were enumerated in Introduction: 1) Interaction with not a computer but a person, 2) Knowing incorrect elements through listening to the performance, and 3) Room for growth.

Please note that the parent's part of FE is actually not the piano but another "new" musical instrument: the way of performance of this part is very different from that of the conventional piano. This is based on a practical decision that the parent need not master to perform the piano: one who should master it is the child. It is also important, however, FE does not intervene with the parent’s musical expression at all. He/she would get to play music with good musical expression as he/she wants through practice. This feature of the parent's part of FE indirectly prompted the child to practice playing the musical instrument. We think that the child also gets to perform more musically through cooperatively constructing musical performance by continuous use of FE with his/her parent.
5. CONCLUSION
We have proposed and implemented a “Family Ensemble” that supports ensemble performances by a pre-instrumental parent and his/her child who has a little experience in playing a musical instrument, specifically, piano. FE will help foster a new cooperative learning method for use at home by parents and children. FE does not directly support the Primo part so it does not detract from the learning process with teachers. On the other hand, FE always tracks where Primo is performing on the score. Using the tracking results, FE supports the Secondo to perform the correct notes. Our score-tracking module is based on Dannenberg’s score-tracking algorithm, but we extended it to cope with a peculiar error of beginners, replaying, in addition to the extra, wrong, and missing types of error that are dealt with by ordinary score-tracking systems. As a result, even if the Primo makes many errors and even if the Secondo has little or no experience in playing the piano, with FE they can immediately enjoy performing duos together. In our experiments, we confirmed that FE facilitates duo play by even the child with a little experience in playing the musical instrument and even the pre-instrumental parent. Furthermore, we found that in the joint practices using FE some subjects discussed musical ideas that helped them achieve richer musical expression. Such a situation was never found in the joint practices without FE because the Secondo, in particular, could consider nothing other than performing his/her part. Thus, FE allows even beginners to aim for richer musical expression. Moreover, the experiments showed that FE prompts children to practice more eagerly.

We would like to conduct more experiments, with more subjects and more musical pieces, at homes and at piano schools as well as at our institute. This will enable us to determine the effect of other environments on the process and assess the long-term usefulness of the system.

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7. REFERENCES