PAPER

Comparison of highly trained and less-trained pianists concerning utilization of auditory feedback

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Abstract: To investigate the features of proficiency in musical performance, we focused on the role of auditory feedback in piano performance and measured its effects in both highly and less-trained pianist groups. In the first experiments, two groups played well-learned pieces under an auditory-feedback condition (performing with sound) as well as no-auditory-feedback condition (performing without sound). The availability of auditory feedback produced no significant differences. In the second experiment, the effectiveness of auditory feedback in the practice stage was investigated. The results revealed that in the practice stage, the less-trained group was more dependent on auditory feedback for controlling the dynamics and agogics than the highly trained group. These results suggest that some performance aspects improved by auditory feedback shifts based on performer skill levels.

Keywords: Piano performance, Auditory feedback, Performance proficiency, Motor control

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1. INTRODUCTION

Musicians must acquire the ability to control musical instruments appropriately to realize refined musical performance. As Gabrielsson [1] states that motor processes are the central function in musical performance, the precise control of a musical instrument or one's voice is required in order to be "skilled" in music. Most musicians spend an enormous amount of time to acquire this motor control.

Motor control studies often argue that sensory feedback is important for effective motor action [2]. It is likely that a similar kind of perceptual feedback plays a crucial role in musical performance. Perceptual feedbacks in musical performance are mainly auditory, visual, and proprioceptive [3], and auditory feedback maintains a position of major importance among them because music is mediated by sounds.

It can be assumed that performers monitor their performance by listening and evaluate the errors between the resultant performance and intended performance, and then properly control it to reduce such errors. This process can be regarded as a typical auditory feedback loop. If a musical performance is executed with this feedback process, deprivation of the auditory feedback will disturb the performance. Several researchers have investigated the role of auditory feedback in musical performance on the basis of this paradigm. Gates and Bradshaw [4] compared organ performances under normal and no auditory feedback condition; and reported no significant differences in terms of total playing time. Banton [5] investigated the roles of auditory and visual feedback in a sight-reading task. Various skilled pianists performed sight-reading tasks under normal, no-visual, and no-auditory-feedback conditions. The results revealed a significant increase in note errors under the no-visual-feedback condition; however the cutting off of auditory feedback did not increase the number of note errors. Finney [6] controlled the existence of auditory feedback to examine the role of sound in the accuracy of the performance; however, no significant effect of the removal of auditory feedback was observed.

To summarize the above studies, which mainly focus on performance accuracy, it can be concluded that the elimination of auditory feedback does not significantly affect performance. This indicates that performers can produce acceptably accurate performance without auditory feedback. However, listeners require more than simply accurate sound transcription of musical notation in a musical performance: they usually appreciate a certain

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level of deviation from notation [7]. This means that performances by professional player differ from the original notation in terms of some performance parameters, such as note duration, timing, and intensity. It seems that such deviations are essential to prevent musical performances from being monotonous and to spice up the performance with the flavor of "expression." As Rosenbaum [8] argued that the quality of a performance without feedback is reduced, feedback information would serve this expressive aspect in musical performance. Repp [9,10] compared the quality of performances under normal and no-feedback conditions. Analysis of the performance parameters relevant to musical expression indicated that a lack of auditory feedback did not significantly disrupt expressive performance.

None of the above studies successfully confirmed that the removal of auditory feedback affected musical performance. Instead, they suggest that the performer did not depend markedly on auditory feedback. This contradicts intuition; however, taking account of the claim that human motor control is carried out with feedforward control when feedback is unavailable [11], the fact that musicians can similarly execute a performance without feedback becomes acceptable if we assume that musical performance can be achieved by a nearly feedforward process [9]. However, it is necessary to investigate the effects of auditory feedback from other viewpoints before concluding that auditory feedback only has a minor role in musical performance.

Before people carry out a performance with any feedforward process, they must acquire information about their performance through feedback learning before reaching that stage [12]. There is also major agreement that sensory feedback is used effectively in the early stages of the acquisition of motor skills [2,13,14]. These insights suggest that the degree of utilization of feedback depends on the level of the performer's experience. In other words, less-skilled performers might depend more on feedback information to execute tasks, while skilled performers could accomplish them to some extent without feedback information. This raises a question: is there any difference in the utilization of auditory feedback between skilled and unskilled players in musical performance? Note that previous studies only analyzed performances from highly trained pianists or only focused on the mean of pooled data even when performances from various levels of pianists were obtained.

In the current study, we conducted comparative performance experiments on highly and less-skilled pianists. By comparing performances with and without auditory feedback to those without in terms of performance parameters, we investigated the differences in the degree of training to realize "expressive" musical performance.

2. EXPERIMENT 1

The first experiment replicated an experiment by Repp [9]. The effects of the removal of auditory feedback were compared between highly and less-trained pianists when playing a well-practiced musical piece. If a performer uses auditory feedback, differences will exist as a result of the presence of auditory feedback. By confirming such differences, we investigated the variations between highly and less-trained pianists concerning their dependence on auditory feedback.

2.1. Participants

Twenty participants took part in Experiment 1. The participants in the highly trained group were five professional pianists and five students who received professional piano training at a university (average years of training is about 27 years, $SD = 8.4$). The participants in the less-trained group were ten students who receive private piano training as a hobby (average years of training is about 14 years, $SD = 3.7$). However, it is difficult to classify the skill of the performer. Taking both groups' learning experience into account, it seems that there was some difference between the two performance groups in terms of quality and quantity of training. Furthermore, in the experimenter's judgment, no participants in the less-trained group seemed to play as well as participants in the highly trained group in the experiment. In the current study, hence, it was considered that there was a certain gap in the performance ability between the two performance groups that were divided by learning experience.

2.2. Musical Material

The musical piece used in Experiment 1 was a short excerpt from an etude for a dotted quarter-note from a famous primer for piano performance in Japan called "Beyer for Children" published by Ongaku-no-Tomo-sha. The musical notation is shown in Fig. 1. This excerpt was selected because it is simple enough even for the less-trained group to play. In the experiment, participants were not allowed to use the sustain pedal because pedaling could create additional difficulties for less-trained participants. No participants had ever played the excerpt in the past. Two weeks before the experiment, participants were given the musical notation and instructed to practice the piece.

2.3. Equipment

Participants performed on a YAMAHA P-250 digital piano with the sound preset to "Grand Piano 1." The auditory feedback was provided through Ultrasone HFI-650 headphones. Under the no-auditory-feedback condition, the headphone plug was disconnected. MIDI data of

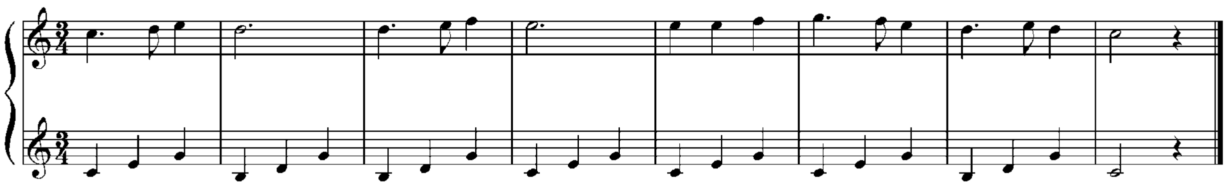

Fig. 1 Musical notation used in Experiment 1.

the performance were recorded onto a MIDI sequencer, YAMAHA QY700, in the standard MIDI file format.

2.4. Procedure

The basic procedure resembled that of experiments conducted by Repp [9]. After warming up on the digital piano, participants played the musical excerpt five times with auditory feedback (AF condition). Next, they played five times without auditory feedback (NF condition). They were instructed to play with their preferred expression, i.e., to avoid strictly mechanical monotonic playing. They were also instructed not to change the expression or interpretation of the musical piece during the experiment to avoid complicating the observation of the effect of auditory feedback. They were allowed to glance at the score during the performance.

2.5. Data Processing

First we extracted the MIDI data of the notes constructing the melody from the MIDI recording. Next, we calculated the average over five performances under both AF and NF conditions for each participant. The averaging process was carried out on each melody note for the following two parameters: (1) key velocity and (2) standardized IOI (Inter Onset Interval; in the current study, IOI means time interval of MIDI note-on timing between two successive notes), i.e., the relative IOI ratio to the metronomic tempo calculated on the performance time.

To obtain an index that represents the degree of mismatch between the performances under the two conditions (AF and NF), we calculated the root mean square (RMS) errors between the two performances for key velocity and standardized IOI for each participant according to the following formulas:

$$RMS_{\mathrm{error}} = \sqrt{\frac{\sum_{i=1}^{n}(v_i - V_i)^2}{n}} \quad (1)$$

$$RMS_{\mathrm{error}} = \sqrt{\frac{\sum_{i=1}^{n-1}(ioi_i - IOI_i)^2}{n-1}} \quad (2)$$

where n is the number of notes constructing the melody part, v_i is the velocity of the ith note in the melody part under the AF condition, V_i is that under the NF condition, ioi_i is the standardized IOI between the ith and $(i+1)$th notes under the AF condition and IOI_i is that under the NF condition. Larger RMS error represents the larger degree of mismatching between the two conditional performances.

All operations, including note extraction for the melodic part, were executed using a Matlab program by referring to the F0 timing information of each note from the musical score.

2.6. Results

2.6.1. Key velocity

Figure 2 depicts the average RMS errors in the key velocity for each skill group. The t-test was performed to compare the RMS errors of the two groups, and no significant difference was obtained ($t(18) = 0.30$, $p = 0.767$).

2.6.2. Standardized IOI

The RMS errors in the standardized IOI for each skill group are shown in Fig. 3. The less-trained group tends to show slightly larger RMS error than the highly trained group. However, the comparison of RMS errors between the two groups by the t-test did not reach a significant level ($t(18) = 2.059$, $p = 0.054$).

2.7. Discussion

The result that there is no significant difference in the

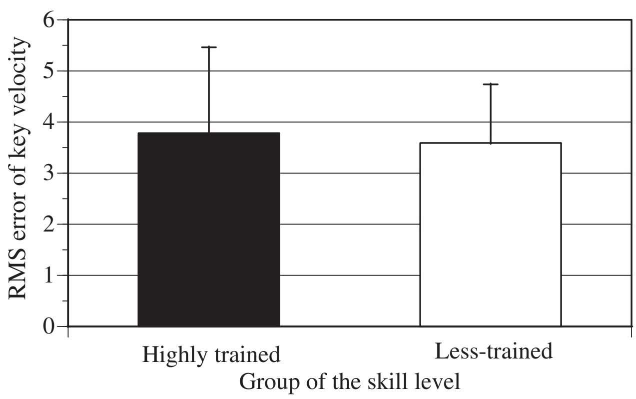

Fig. 2 Average RMS errors in key velocity for each skill group. Black and white bars indicate results for highly and less-trained groups, respectively. Error bars represent standard deviation. Higher RMS error indicates lower consistency of AF and NF conditions.

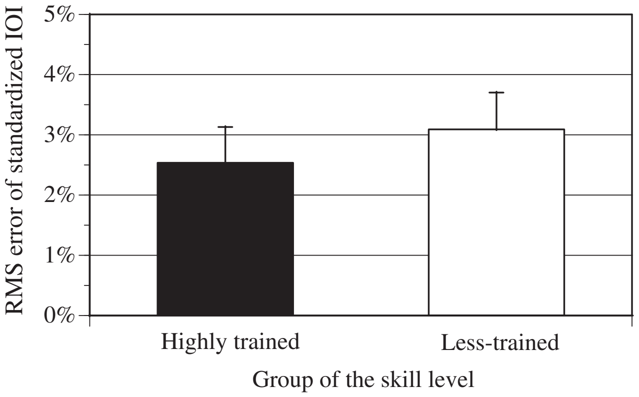

Fig. 3 Average RMS errors in standardized IOI for each skill group. Black and white bars indicate the results for highly trained and less-trained groups, respectively. Error bars represent standard deviation. Higher RMS error indicates lower consistency of AF and NF conditions.

RMS errors between the highly and less-trained groups indicates that auditory feedback plays no significant role in controlling piano performance for less-trained as well as highly trained musicians.

This result, which does not support our assumption that the effect of eliminating auditory feedback would differ depending on training degree, suggests that musical performance is mostly carried out with a feedforward rather than a feedback process. Considering the assertion that most coordinative and overlearned motor control requires a feedforward process, the result of Experiment 1 is plausible, assuming that even the less-trained pianists had acquired a certain level of the feedforward process for the piece as a result of practice before the test. If the feedforward process were established through practice, one could argue that the feedback process might be more active in the practice phase than in the final phase. Experimental evidence also suggests the importance of feedback in practice. Finney and Palmer [15] reported that the existence of auditory feedback in practice improved the ability to memorize the musical performance.

The observations in Experiment 1 and previous studies are based on the performance of a well-practiced piece. The performers had probably already acquired the proper motor control for the target musical piece used in the experiment as a result of practice. Therefore, the deprivation of auditory feedback did not clearly affect output. On the basis of these reasons, we focused on the effectiveness of auditory feedback in the practice phase and its relation to performer skill levels in Experiment 2.

3. EXPERIMENT 2

In Experiment 2, we set up practice situations where pianists imitated a model performance. It seems that this situation is not far from the actual practice process, because learners often try to imitate good performances. The presence of auditory feedback during such practice was one of the main experimental parameters. If a performer depends on auditory feedback information, they will produce an inferior imitation of the model under NF conditions than under AF conditions. Accordingly, the difference between AF and NF conditions can indicate the level of dependence on auditory feedback. The dependence on auditory feedback in the practice phase was compared between the highly and less-trained groups. This training degree was the second main experimental parameter.

3.1. Participants

Thirty-six participants took part in the experiment. The participants of the highly trained group were eighteen students who studied piano performance at a university (average years of training is about 19 years, $SD = 2.0$), and the participants of the less-trained group were eighteen high school and university students who only receive private piano training as a hobby (average years of training is about 10 years, $SD = 3.5$).

Half of the participants in each group was randomly assigned to the AF condition, while the other half was assigned to the NF condition.

3.2. Musical Material

To ensure a reasonably equivalent difficulty of the performance task for the two groups with different skill levels, two different musical pieces were chosen from a training book for the sight-reading test of the YAMAHA Grade Examination conducted in Japan. The material for the highly trained group was a short excerpt from the 4th grade training book, and for the less-trained group, it was one from the 8th grade book. (Note that a lower grade denotes a more advanced level). No participants had ever played the excerpts in the past. All expression marks were deleted from the musical notation presented to participants. The two musical notations are shown in Fig. 4.

3.3. Equipment

Participants played the task pieces using a YAMAHA P-90 digital piano in the two-channel multitimbre mode, and we assigned channel A to manual playing and channel B to replaying of the model performance (see below). The sound was preset to "Grand Piano 1" for both channels. Participants listened to the sound through Sennheiser HD-600 headphones connected to the digital piano. The MIDI local mode of channel A was turned off under the NF condition. Performance data were recorded onto a MIDI sequencer, YAMAHA QY700, in a standard MIDI file format.

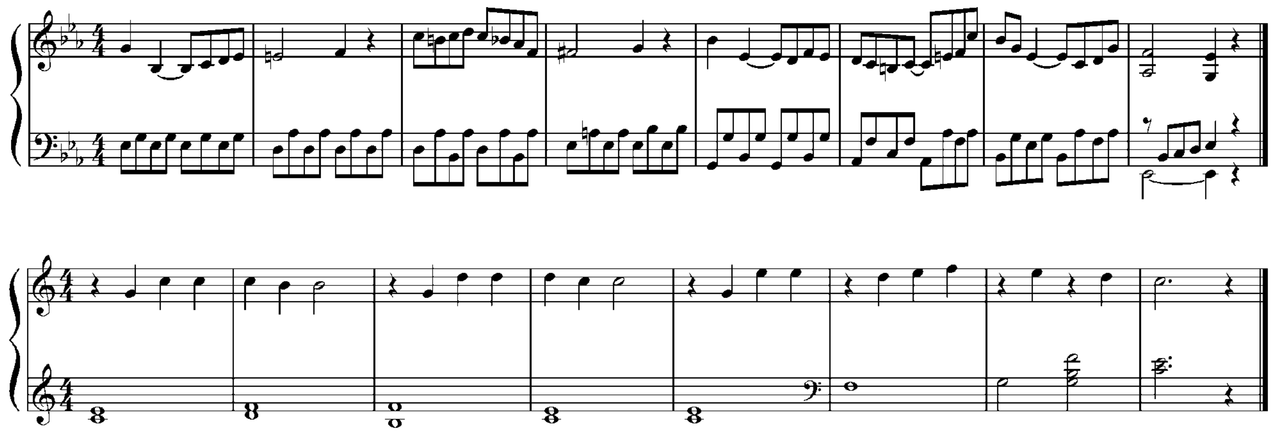

Fig. 4 Musical notations used in Experiment 2. Top and bottom show pieces for highly and less-trained groups, respectively.

3.4. Model Performance

In this experiment, two model performances were prepared as target performances for participants. A metronomic model performance was generated by the MIDI sequencer with three performance parameters: tempo, key velocity, and duration ratio, fixed at invariable values. An expressive model performance was prepared by recording the performance MIDI data of the musical piece played by a professional pianist who was instructed to play with "typical" expression. Because of the fact that both excerpts seem to have some similar musical features (chord progression, specific separation between melody and accompaniment and so forth), it can be regarded that there was little difference in the degree of expression between the two performances in the expressive model.

During practice sessions in the experiment, participants were allowed to listen to the model performance freely via the MIDI sequencer, YAMAHA QX3, connected to the digital piano.

3.5. Procedure

The experiment consisted of four sessions: (1) baseline practice, (2) pretest, (3) experimental practice, and (4) post-test. The baseline practice session functioned as an initial control of conditions for participant familiarity with the musical excerpt before succeeding sessions. In this session, participants listened to the metronomic model performance as many times as they felt necessary and practiced freely to imitate the model as closely as possible. In subsequent pretest sessions, participant played the musical piece two times, and performance data were recorded. In both the baseline practice and pretest sessions, all participants, regardless of condition, listened to what they played on the digital piano in real time through headphones. In the next experimental practice session, participants listened to the expressive model performance and practiced imitating it as closely as possible. The time frequency of listening to the expressive model was free, however, there was no statistically significant difference among the four conditional groups in the time frequency of listening to the model performance in the experimental practice session (the average values of the time frequency of listening were 14.4 and 11.4 for the highly trained and the less-trained AF condition, respectively, and 11.0 and 11.5 for the highly trained and the less-trained NF condition, respectively). Hence, it cannot be reasonably assumed that the experimental parameters (performers' skill and feedback condition) would have affected the performers' practice motivation. They were allowed to practice ten times under assigned practice conditions. AF condition participants were allowed to listen to what they played in real time, while NF condition participants could not listen to the "tones" of the MIDI piano. In a precise sense, they could listen to the sounds made when each keyboard was hit, although the level of such sounds were attenuated by the headsets. Movement of the fingers while listening to the expressive model was prohibited. In the last post-test sessions, participants played the musical piece two times with auditory feedback, and performance data were recorded. Participants were allowed to glance at the score during the performance.

3.6. Data Processing

As in Experiment 1, first the melody was extracted from the MIDI recordings, and then the averages of each of the two performances recorded in the pre- and post-test sessions were calculated for each participant for key velocity and standardized IOI.

To estimate the deviation from each model performance, RMS errors from the model performance were calculated for each of the pre- and post-test performances for each participant for the velocity as well as for standardized IOI. The averaged data for each participant were used as v_i and ioi_i in Eqs. (1) and (2), respectively, in calculating RMS errors. V_i and IOI_i were those of each model performance, i.e., the metronomic one for the pretest and the expressive one for the post-test, respectively. Larger RMS error represents a lower achievement in imitating the model performance. All analytical operations were performed by a Matlab program by referring to the information of the provided musical score.

3.7. Results

3.7.1. Pretest session

3.7.1.1. Key velocity

Figure 5 depicts the average RMS errors on the key velocity for each conditional group in the pretest sessions. We performed a two-way ANOVA with skill class (highly and less-trained) and practice condition (AF and NF conditions) as factors. Only the effect of the skill class factor was significant ($F(1,32) = 26.283$, $p < 0.001$). Although a significant effect of the practice condition factor and interaction between these two main factors were not observed, a slight difference seems to exist in the RMS errors between AF and NF conditions in the less-trained group. To guarantee no unexpected prebias between the test condition groups, separate t-tests with Bonfferoni correction (significant level $p = 0.05/2 = 0.025$) were carried out for both skill classes to investigate the difference between AF and NF conditions. No significant difference was observed in either of the skill classes.

3.7.1.2. Standardized IOI

Figure 6 indicates the average RMS errors in the standardized IOI for each conditional group in the pretest sessions. RMS errors are almost equivalent under the two practice conditions as well as for the two skill classes. A two-way ANOVA with skill class and practice condition as factors only revealed a significant effect of the skill class factor ($F(1, 32) = 287.624$, $p < 0.001$). Separate t-tests with Bonfferoni correction ($p = 0.025$) did not reveal any significant difference between AF and NF conditions in either skill group.

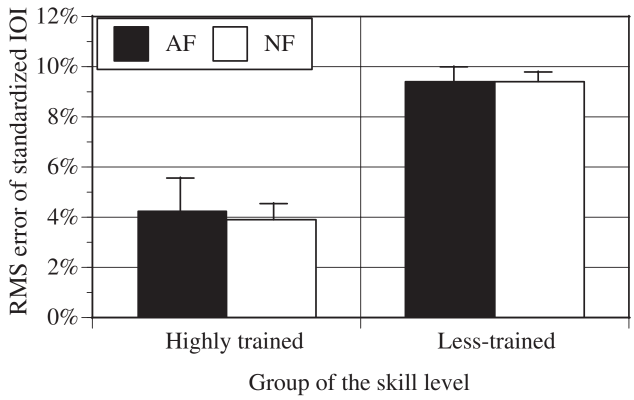

Fig. 6 Average RMS errors in standardized IOI under each condition in pretest sessions. Left side depicts results for highly trained group and right side depicts those for less-trained group. Black and white bars indicate AF and NF conditions, respectively. Error bars represent standard deviation. Higher RMS error indicates lower consistency with the metronomic model performance.

3.7.2. The post-test session

3.7.2.1. Key velocity

Average RMS errors in the key velocity for each conditional group in post-test sessions are shown in Fig. 7. A two-way ANOVA was performed with skill class and practice condition as factors, and the effects of skill class ($F(1, 32) = 16.664$, $p < 0.001$) and practice condition

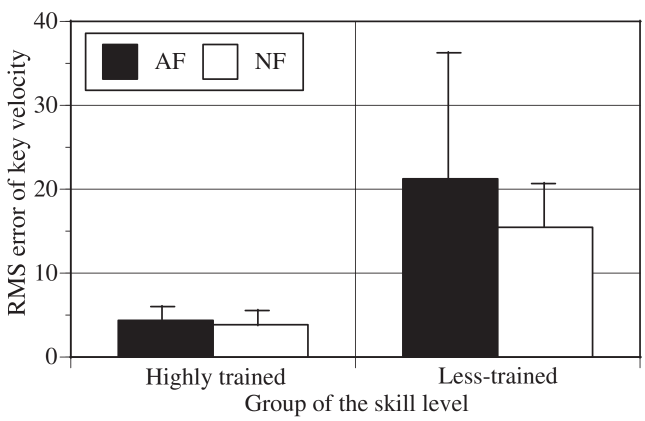

Fig. 5 Average RMS errors in key velocity under each condition pretest sessions. Left side depicts results for highly trained group and right side depicts those for less-trained group. Black and white bars indicate AF and NF conditions, respectively. Error bars represent standard deviation. Higher RMS error indicates lower consistency with the metronomic model performance.

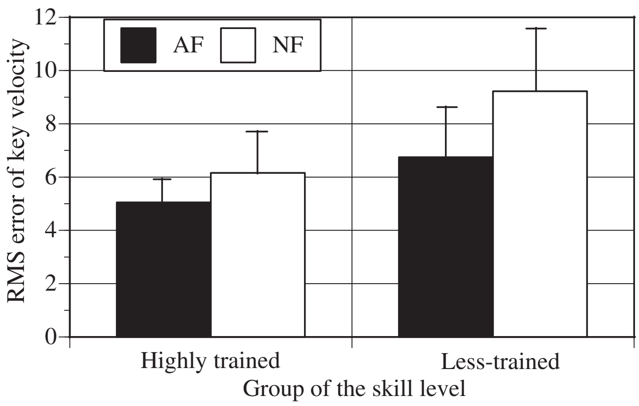

Fig. 7 Average RMS errors in key velocity under each condition in post-test sessions. Left side depicts results for highly trained group and right side depicts those for less-trained group. Black and white bars indicate AF and NF conditions, respectively. The error bars represent standard deviation. Higher RMS error indicates lower consistency with the metronomic model performance.

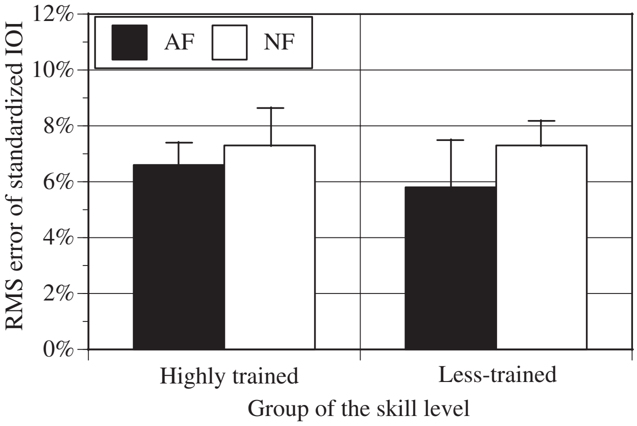

Fig. 8 Average RMS errors in standardized IOI under each condition in post-test sessions. Left side depicts results for highly trained group and right side depicts those for less-trained group. Black and white bars indicate AF and NF conditions, respectively. Error bars represent standard deviation. Higher RMS error represents lower consistency with the metronomic model performance.

($F(1, 32) = 9.443$, $p = 0.004$) were found to be significant. Interaction between the two main factors was not significant; however the differences between AF and NF conditions seem to be larger in the less-trained group compared with the highly trained group. Therefore, separate t-tests with Bonfferoni correction ($p = 0.025$) were performed for each skill group to compare differences between AF and NF conditions. A significant difference was observed only in the less-trained group ($t(18) = 2.505$, $p = 0.023$).

3.7.2.2. Standardized IOI

Figure 8 depicts the average RMS error in the standardized IOI for each skill group in post-test sessions. A two-way ANOVA with skill class and practice condition as the main factors confirmed only a significant effect of the skill class factor ($F(1, 32) = 7.979$, $p = 0.008$). However, as in the case of key velocity, the differences between AF and NF conditions appeared slightly larger in the less-trained group than in the highly trained group. Therefore, separate t-tests with Bonfferoni correction ($p = 0.025$) were carried out to compare the AF condition with the NF condition for each of the skill groups. As a result, a significant difference between AF and NF conditions was observed only in the less-trained group ($t(18) = 2.549$, $p = 0.021$).

3.8. Discussion

The pretest session results in which no significant differences were found between the AF and NF conditions ensured that there were no unexpected differences in the initial status before experimental practice sessions. Significant differences between the AF and NF conditions being observed in post-test sessions indicate that the availability of auditory feedback in the practice phase affected the achievement in the final stage. This result is consistent with those of Finney and Palmer [15] who argued that auditory feedback plays an effective role in the practice phase.

Also, significant differences between AF and NF conditions in post-test sessions were observed only in the less-trained group; i.e., the NF group imitated the model performance worse than the AF group in the less-trained group. This suggests that there are some differences in the dependence on auditory feedback depending on the skill of the performer.

4. GENERAL DISCUSSION

In Experiment 1, no significant effect of the lack of auditory feedback was observed. The performance without auditory feedback barely differed from the performance with auditory feedback for both highly and less-trained participants. This suggests that the performance of well-learned pieces was mostly executed with a feedforward process. Even for less-trained participants, disregarding the musical (or aesthetic) quality of their performance, their motor control became at least stable enough as a result of the practice allowed before test sessions.

However, the results of Experiment 2 confirmed the effectiveness of depriving auditory feedback in practice phases. The less-trained group was significantly hampered in imitating the expressive model performance when deprived of auditory feedback, indicating that auditory feedback in the practice phase is crucial for acquiring fine motor control related to musical expression. Although, in the current experiment, we could not find a significant effect of the deprivation of auditory feedback in the highly trained group, this result does not mean that the highly trained pianists could always produce proper motor control without auditory feedback. If they must acquire a new motor skill for themselves, they also would use auditory feedback effectively in practice phases. It may be that no clear effect of the deprivation of auditory feedback was observed in the highly trained group because the musical piece in Experiment 2 was too easy for them.

The results of Experiment 1 and 2 suggest that the control process of playing the piano shifts from feedback to feedforward with an increase in the performers' proficiency in playing the target musical piece. A performer probably makes his/her movements on the musical instrument finer and smoother by trial and error through practice, which contributes to a stable performance.

The difference between the highly and less-trained groups in Experiment 2 suggests that the dependence on auditory feedback in the practice phase is a sensible indicator of the skill class of the performer. The results of our current study suggest the following. If the skill class is defined as the degree of feedforward control, skilled performers have likely acquired a sufficient number of mapping functions between their actions and the resultant sounds. For example, one could assume that the mapping of the timing relations between key depression and sound onset is rather primitive, and which has even been acquired by the less-trained group in this study. In contrast, the acquisition of mapping between key depression and sound intensity might be rather difficult and complicated owing to the variation in instruments and environment. Therefore, the requirement of experience would become important compared with the relationship between key depression and sound onset. Because skilled performers rely on established mapping, they require less auditory feedback as a result of practice than unskilled performers. In contrast, unskilled performers require auditory feedback to erect new mappings, and renew or revise incomplete mappings.

It can be assumed that such mapping functions are formed through conscientious training with various musical pieces. The difference in the comprehension of such relationships seemed to cause the differences between the highly and less-trained groups in Experiment 2. Therefore, the degree of dependence on auditory feedback information is one feature that reflects the performer's level of skill.

It could be argued that the limited variation of musical excerpts used in the current experiments restrict the formulation of a general conclusion. However, taking account of previous arguments on the relationship between human motor control and its developmental aspects, the current results do not contradict the general ideas in the domain of skill acquisition.

5. CONCLUSION

The differences between highly and less-trained pianists in their utilization of auditory feedback were investigated. A significant difference depending on skill was observed during the practice phase. From this result, we conclude the following about the utilization of auditory feedback and its relationship to the performer's skill in piano performance. Auditory feedback in piano performance is effective particularly in practice to acquire the proper control of the musical instrument. The dependence on auditory feedback in such situations could differ based on the performer's skill. After sufficient practice, performance was carried out mostly with feedforward control, and the effect of the deprivation of auditory feedback became more difficult to observe regardless of the skill level.

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