Practice Stages for a Proficient Piano Player to Complete a Piece: Understanding the Process based on Two Minds

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***Abstract*— Research into instrumental music performance has garnered significant attention, particularly regarding the intricate interplay of perceptual-cognitive-motor interactions, knowledge application, and the cognitive representation of musical structure. Understanding these dynamics holds promise for enhancing instruction and aiding learners in their journey towards mastering instrumental performance and practice. However, grasping the learning process necessitates more than just comprehending the individual cognitive mechanisms at play; it requires a holistic approach that considers the cognitive architecture enabling the integration of these processes. In this paper, based on the MHP/RT framework proposed by Kitajima and CCE research method which based on the MHP/RT principles, we attempt to understand the process of proficiency in music performance by proficient piano players as a brain model based on the coordination of perception, cognition, and movement, and the concept of Two Mind. Initially, we modeled the cognitive process of piano performance proficiency, and ethnographically described the process of proficiency in music performance for selected elite monitors. The descriptions are analyzed and compared with the model of cognitive processes and actual behaviors in performance proficiency. The description of which perspectives can/cannot be interpreted by the model based on the MHP/RT were considered. Finally, a series of piano playing exercises and lessons are analyzed from the perspectives of the Two Minds process, and the knowledge system (implicit/explicit) utilized. Through the analysis, the relationship between acquired knowledge and cognitive ability and Two Minds is considered. The findings suggest that the proficiency process of instrumental music performance exhibits a kind of phase transition. It involves not only a gradual shift from prolonged, System 2-driven mechanical training towards an intuitive, System 1-driven unconscious expression but also deviations from this pattern. Therefore, it is imperative for players to thoroughly comprehend their perception of the entire piece (System 2) while also fostering a sense of ease and naturalness in performance akin to unconscious expression (System 1) for the listener.**

Keywords: Proficient Piano Player; Cognitive Process; Two Minds; MHP/RT; Ethnological Study;

I. INTRODUCTION

Instrumental performance has attracted attention as a result of the interaction of perceptual/cognitive and motor abilities. Numerous studies focus on the process of instrumental performance proficiency. The goal of this study is to understand the proficiency process of instrumental performance, which has the possibility of providing better instruction to a performance learner.

Palmer [1] summarizes empirical research on instrumental performance in terms of conceptual interpretation formation, control over motor actions, interpretive transfer as perception, and structural disambiguation. Lehmann and Ericsson [2] focus on the development of instrumental performance skills at the level reached by high school students and amateurs. In their study, they posit that the method of practice is particularly important in improving the level of instrumental performance. A study that focused on the subjectivity factor of instrumental performance practice itself, shares a different perspective; Araújo [3] conducted an online questionnaire survey of self-regulated practice behaviors pertaining to advanced musicians, from which, he indicates that practice organization, personal resources, and external resources are important factors. For understanding proficiency in instrumental performance, Chaffin et al. [4][5] applied the protocol analysis method, investigating the characteristics of a concert pianist's performance of a piece of music, in addition to the characteristics of the music. They categorized elements of the instrumental performance in three basic dimensions (fingering, high difficulty, and familiarity with the note form), four interpretive dimensions (phrasing, dynamics, tempo, pedal), and three expressive dimensions (basic, interpretative, expressive). Through the categorization process, a possibility of the existence of image for desired representation of the music from the beginning, so-called a "*big picture*" was found.

Focusing on how to practice instrumental music performance, as Palmer [1] mentioned, an individual's cognitive representation of musical structure is important in terms of specific errors and knowledge utilization in instrumental music performance. To understand this, it is not only sufficient to understand the cognitive mechanisms for individual perceptual, cognitive, and motor processes, but also research from the perspective of cognitive architecture, which enables these processes to be handled in an integrated manner.

There are several cognitive architectures concerning the interaction between perceptual/cognitive and motor abilities, however, we apply the Model Human Processor with Realtime Constraints (MHP/RT) proposed by Kitajima et al. [6][7][8] for this study. MHP/RT is a cognitive architecture, which is constructed by extending the concept of Two Minds (Kahneman [9][10]) to reproduce the perceptual, cognitive, and motor processes as well as memory processes at work in

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everyday action selection. The MHP/RT has been applied to the comprehension of language utilization and the process of creating ceramic artworks [11][12]. For the latter study, the MHP/RT is applied with a companion field study methodology called Cognitive Chrono-Ethnography (CCE) [8][13]. CCE is a research methodology utilized to clarify the process of development concerning how a specific individual has acquired the behavior selection characteristics at the present time, and the development process of the behavior selection characteristics at the site where the behavior is executed based on the behavior selection mechanism on a time axis, which is specified by the MHP/RT. The implementation of CCE requires appropriate subjects – elite monitors – who are ideal subjects for the purpose of the particular research.

In this article, we attempt to understand the process of proficiency in music performance by applying CCE, underpinned by the MHP/RT's underlying concept of the Two Minds, such as the interplay between the unconscious process of System 1 and conscious process of System 2. In Section II, the cognitive process in piano performance proficiency based on the MHP/RT is modeled, which provides the basis of the CCE. In Section III, the process of proficiency in music performance for selected elite monitors is described. In Section IV, the cognitive process model and actual behavior in performance proficiency is compared, and the points that can be interpreted by the model, the points that cannot be interpreted by the model, and the implications from the MHP/RT perspective are thoroughly discussed.

II. Cognitive Processes Leading to Proficiency in Piano Performance

Playing piano involves processes such as reading the score and creating its mental representations and retrieving knowledge from long-term memory related to the representation, which comprise a variety of information necessary to establish links between the representation of visual information on the score and the concrete hand/finger movements to be conducted on the instrument. Long-term memory consists of chunks for establishing these links, which develop with practice from an initial configuration with inefficient linkage to an advanced one with effective linkage, corresponding to the state of proficiency. This section provides a theoretical description for the development process of the chunk structure.

A. Initial State: Initial Chunks in Long-Term Memory

The chunk structure, within long-term memory at the beginning of reading a score, is a set of chunks that have been acquired as knowledge and stored in long-term memory. Let C_{mus} be the chunk set that must be stored, the chunk set C_{LM} that exists in long-term memory at a certain time t is a subset of C_{mus}. C_{mus} is composed of the following, based on the smallest element c_i $(1 \leq i \leq n_c(t))$:

- Chunks composed of the minimum element $n_c(t)$ only,
- Larger chunks composed of $n_e(t)$ $(1 < n_e \leq n_c)$ minimum elements, without duplication, and

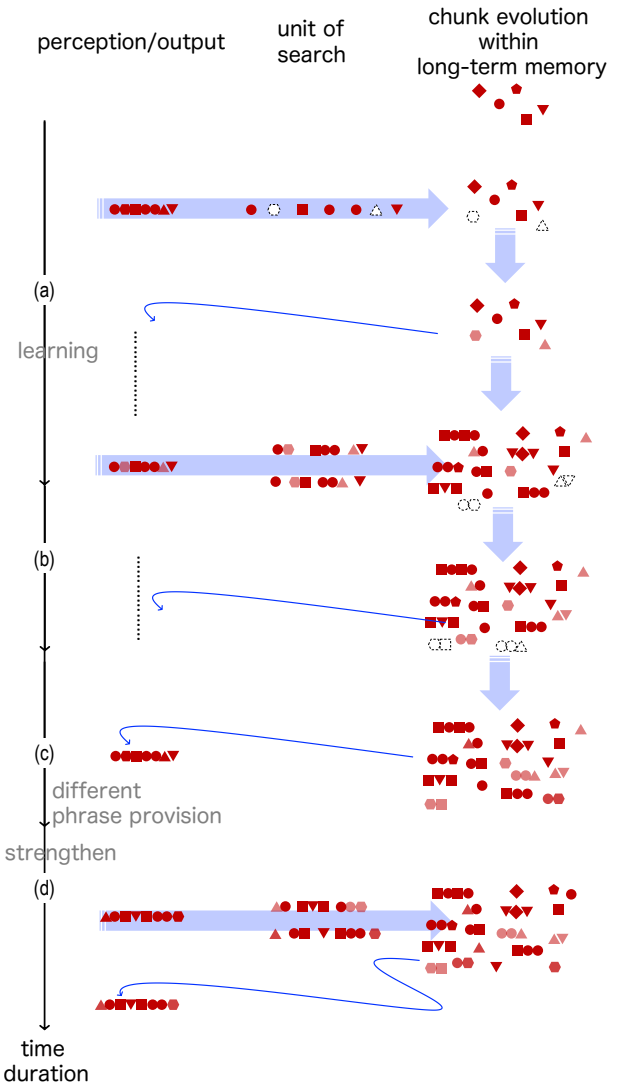

Figure 1. The relation between perception/ourput and chunk evolution within long-term memory

- Still larger chunks consisting of $n_{e'}(t)$ $(1 < n'_e \leq n_c)$ minimum elements, with duplication allowed.

In addition, C_{LM} consists of the relation:

$$C_{LM} \quad = \quad \{\boldsymbol{c} \mid c_i \in C_{mus},\ 1 \leq i \leq n_{LM}(t)\}$$

The internal structure of C_{LM} evolves as a learning and strengthening process as the number of chunks it contains increases with practice.

B. State (a): Recognition of Individual Notes or Short Phrases

When reading a new score of music, the perceived sequence of notes is divided into known notes or short phrases. When the learner encounters an unknown phrase, it is stored as a new chunk. The layer (a) in Figure 1 exhibits this state. A sequence of notes $S(t)$ perceived at t consists of n_p elements. When $S(t)$ is initially read, $S(t)$ is separated by n_p individual chunks c_j, and the score reading process commences. When an unknown element $c_{j'}$ appears, $c_{j'}$ is newly stored in long-term

memory (black dashed line in the figure). As the score reading proceeds in this manner, the reading of each n_p element proceeds smoothly, and the newly stored $c_{j'}$ is additionally stored and fixed in memory. In this state, the learner plays these phrases with a pause – each c_j plays with intermittent, so that it can only be played with an awareness of partial cohesion.

C. State (b) and (c): Recognizing Multiple Chunks Simultaneously

When a sequence of notes can be recognized as individual notes or short phrases, the same $S(t)$ is perceived, but several c_j are lumped together and recognized as a novel chunk (phrase) in order to play the music significantly smoother. The layer (b) in Figure 1 exhibits this state. When the learner perceives this unknown combination of c_j's as a set, it is stored as a new chunk (black dashed line in the figure). At this time, the size of the chunk is larger than that of the state (a), enabling the learner to perform with an awareness of longer chunks. In order to be aware of the large phrases, training is also conducted to recognize $S(t)$ more reliably by separating the elements of $S(t)$, and c_j's, in various ways. When the learner perceives an unknown c_j combination, the combination is newly stored in the long-term memory (black dashed figure in Figure 1). Through repeated training, the number of chunks (phrases) formed by the combination of c_j that existed prior to the training increases in long-term memory, and the learner's chunk set structure incrementally approaches C_{mus}. Finally, the learner's chunk set structure in long-term memory is reached at the state (c), and the presented sequence of notes can be recognized as a single chunk. If the learner's condition reaches the state (c), the learner's skill is regarded as "acquiring the ability to perform $S(t)$ with proficiency."

D. State (d): Efforts toward more Reliable Chunking

When the structure of C_{LM} is saturated, even if a sequence of notes is novel to the user, it can be perceived as a known sequence of notes by devising alternative segmentations for c_j. Assuming that a new sequence of notes $S(t')$ consisting only of chunk groups in C_{LM} is perceived, in this regard, the recognition of $S(t')$ is divided by utilizing the chunk elements in long-term memory. Since all the chunks are known, reading will commence without much effort being required. The layer (d) in Figure 1 exhibits this state. In this case, the chunks in long-term memory are simply strengthened.

E. Summary

As the above state is repeated, more C_{LM} is accumulated in long-term memory, and even when it is presented with a complex piece of music, the user can be confident that "this musical piece can be performed". Therefore, as C_{LM} increases in the fasion described above, the more musical pieces the learner practices, the more proficient the learner becomes, and the more musical pieces the learner is able to perform. However, in actual performance, there are two types of practice: one is to perform without making mistakes even if it takes a longer time, i.e., a phase of musical score reading, and the other is to perform without stopping to have the audience experience a smooth performance. A performance aimed at continuously avoiding mistakes involves different cognitive processes in terms of System 1 and System 2. System 1 is controlled by the feed-forward process and is compatible with the latter; while System 2 is controlled by the feedback process, i.e., the conscious process that monitors the outcome of System 1's performance to correct any errors, and is compatible with the former. The process of utilizing chunks should be different in these cases. The next section describes an example of how the cognitive processes, leading to performance proficiency described above, appears in actual performance proficiency.

III. An Example of Proficiency Process of Music Performance by a Proficient Piano Player

In this section, we describe a CCE study focusing on a single elite monitor, following the study conducted by Kitajima et al. [12] to understand the skill of a traditional craft artist and how the skill is passed down from generation to generation, as well as how the process by which a proficient piano player reaches the expected performance level through practice of a given piece of music. We call the elite monitor, i.e., the proficient amateur piano performer, P^3, and consider the situation where P^3 tries to achieve a high level of performance perfection through practice. The characteristics of the score that P^3 is aiming for, i.e., the target score abbreviated as TS, with reference to P^3's performance skill level is elucidated. Subsequently, the study enumerates the elements included in the practice to be conducted to achieve TS, and elucidate the development of the practice over time and the content of the practice elements associated with it.

Here, the role of P^3 is taken by the first author. The core of the CCE analysis – describing P^3's experience – has operated as stated below. In order to avoid a biased analysis, when P^3 made an ethnographic analysis, P^3 asked the instructor the meaning of musical suggestion or cognitive meaning with regard to playing piano training method given by instructor. For representation of the CCE analysis, P^3 wrote down the experience series and the initial proposed model. Subsequently, the other two authors, who are professionals with the CCE, meticulously investigated the proposed model which P^3 proposed. Finally, the authors adopt the representation which all authors judged to be acceptable.

A. Main Objectives of a Skilled Piano Learner

In general, there are two main objectives when an adult learner attempts to acquire proficiency in musical performance.

1) Internal factor, such as genuinely wishing to become proficient for strong motives, e.g., favorite piece of music, wanting to perform it, and select a piece for a competition, etc.
2) External factor, i.e., a piece assigned for a competition or given for practice

It depends on which objective the learner set, but here we target the "to be made best performance at the competition" in 1). In this instance, P^3 can select a piece of his/her own will, but the target performance achievement is to pass at least the regional qualifying round of the piano competition (with a required score is 70/80 or higher), and preferably the regional finals (with a required score is 80/86 or higher).

B. Flow of Music Proficiency to Reach Competition Stage

Figure 2 represents the general proficiency process of a musical performance. Given that it takes a long time, anywhere from six months to one year, to become proficient in a music performance, the most important process is the selection of the music to be performed. Basically, there are two important perspectives of selection with regards to music and performing: whether or not the piece is appropriate for the player's performance skill level, and whether or not the player prefers the piece. However, in the case of P^3 who can participate in competitions, there is a lot of freedom in music selection, which means the performance skill level is not a constraint. Hence, P^3 asked her instructor for several candidate pieces that would be suitable for her own timbre and expressive characteristics. On top of that, P^3 herself selected the music to be performed through the following process：

- Give the score a once-over,
- Try out playing the initial few pages (where most of the music motifs are available), and confirming whether or not they can play the piece to the end, and
- Listen to a professional performance and determine if you can grasp the image of the piece.

After the piece for competition is selected, the learner practices playing it to the end so that the framework of the piece can be imagined. Then, the learner makes *Analise* with the outcome of practice. Post-completing the *Analise*, she fixes the image that expresses fluent performance, and additional interpretation as well as the necessary skills for performance expression. Subsequently, she will go to the competition performance. Details of each process are described in the subsections to follow.

C. Details of the Processes and Mapping on Two Minds

1) Score Selection toward Practice: There are various ways to select a music piece for competition. In a competition which is not given a set piece of music and in which the goal is to perform well in the competition qualifying round and the finals, there are a number of points to consider in the selection of the music piece. In addition to selecting pieces and considering the level of difficulty, there are some other selection points. In the case of P^3, the following procedure was utilized to select pieces at an appropriate level.

1) Ask her instructor to list some candidate pieces:
   There are two reasons for this. One is to avoid selecting pieces of an inappropriate level for the competition. The other is to have an outsider recommend a piece that is suitable for the color of P^3 from a third party's perspective.
2) Read the scores giving a once-over to the end to get an image of the music, and narrow down the candidate pieces to 2∼3:
   In the case of P^3, the key points in narrowing down the candidate pieces are basically two points : whether the feeling of the music fits, and whether the image of the music can be grasped by reading the scores once-over.
3) Read and perform the initial few pages of the piece (up to the point where the initial and subsequent motifs appear):
   The mechanics utilized in the actual performance are quite different from the image, and even if the instructor thinks "She can perform this," it is rare for P^3 to find with the mechanics that "her cognitive or motor reaction rejects".This process is designed to prevent such mismatches.
4) Select a piece of music that she is convinced she could perform well.
   In the case of P^3, the selection is made focusing on the music that immediately comes to mind concerning "what she wants to express" when the motifs are performed.

Thus, the selection of music, which is the initial step in music practice, is often determined to a large extent from a System 1 perspective. However, in order for System 1 to function, the skills that the body has acquired are as a result of long-term System 2 training. This is because it is necessary to determine which of the chunk configurations (a)∼(d) in Figure 1 are utilized in the piece, and to start from the point where she checks the degree of practice required to become proficient at the piece. If the majority of the motifs are in the state exhibited in Figure 1(a), it will take a considerable period of time to become proficient in the piece, and depending on the situation, the player may have to give up. It is also difficult to receive assurance that "I can perform the piece". Figure 1(b) and (c) are more likely to be able to perform with the music with proficiency, as it is easy to obtain the confidence that "I can perform the piece". Therefore, it is expected to be the target of music selection.

2) Transition of Instructional Contents: The process required to complete a musical performance can be divided into two main categories: musical score reading and compositional expression. The musical score reading is a practice stage in which mechanics – motor system – play a major role. Compositional expression practice is the stage, where musical interpretation, i.e., the player's expression tailored to his/her sensitivity, and technique for the expression, plays a major role. There are significant disparities between the two practices.

In the case of mechanically trained music reading, the focus is on accurate keystroke execution. Therefore, the main task of practice is to reproduce the exact note value, pitch, and interval for each note head. In simple words, the primary focus of practice is to count the lengths accurately, to check the details of pitches, and pitches described in the score, and to check accidentals, articulation marks, ornaments, pedal marks, etc. The utilization of knowledge in this process is basically

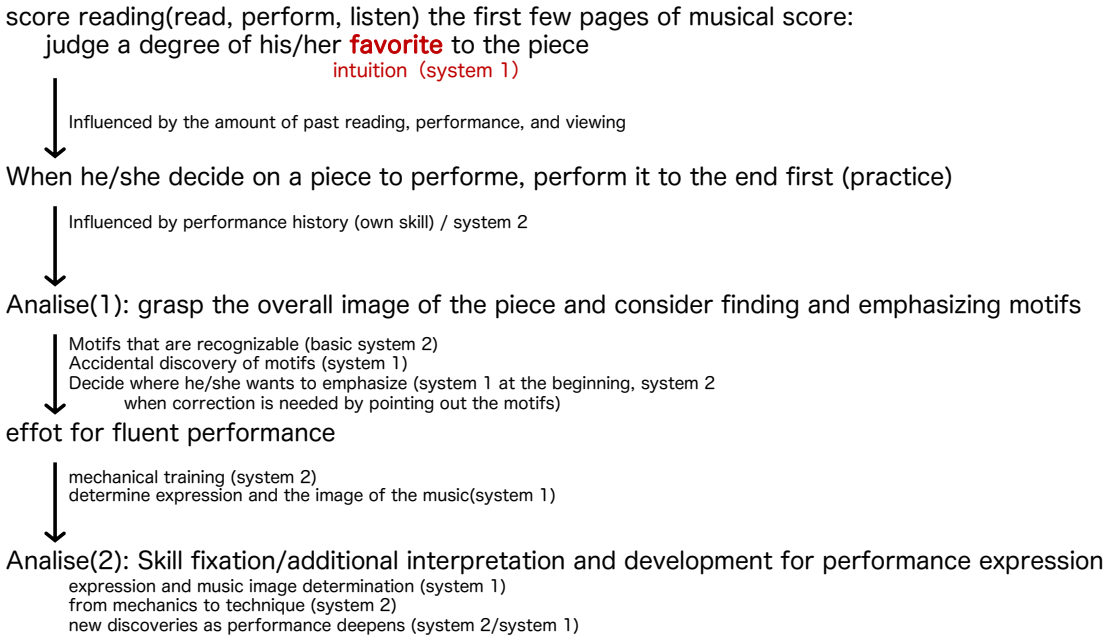

Figure 2. Flow to proficiency in music performance

centered on (a) and (b) in Figure 1, and is mainly a System 2 process in terms of practicing to play the sequence of notes exactly as described in the score.

Conversely, in the case of the musical score reading, which trains techniques for compositional expression, a variety of control with regards to the fingers and cognition is required, such as how far to play a note sequence as a whole, how to add dynamics, and which notes to insist on. Simply put, it is a prerequisite that the player has already finished *Analise* the piece and that the player's image of the entire piece has been established. The two elements are not independent, which means the existence of accurate mechanics enables the player to confidently express music utilizing this technique.

It is also necessary to learn the mechanics required to make the technique more precise, for example, the dynamic technique and the techniques required to change timbre. In this sense, it is a cooperative activity between cognitive and motor processes. When teaching these cooperative activities, the instructor decides on the contents of instruction in the following manner with regards to listening to the player's performance.

- Understand what the player wants to emphasize and what kind of expression he/she wants to express from the performance.
- Imagine what the player wants to do but does not seem to be able to do.
- Point out obvious deviations from the interpretation of the performance as described in the score, and give a more natural interpretation.

Of course, if a player has sufficient ability, he/she can improve these items by self-regulation post-recording his/her own performance. However, different from students who are beginners when it comes to performing, there is a limit to self-regulation improvement in the field where advanced performance is required. For this reason, suggestions from the instructor play an important role for a player's proficiency.

The instructor suggests more exercises that would contribute to the formation of chunks as opposed to the movement. For instance, changing the playing speed between stressed and unstressed parts (contributes to the formation of chunks), practicing rhythm (contributes to the formation of fingering chunks), and giving more accent than necessary to notes that should be emphasized (contributes to the formation of chunks in the imagery of the music). The primary utilization of knowledge in such exercises is exhibited in Figure 1 (c), and primarily consists of combining the smallest elements c_j that may appear in a piece of music in as long a phrase as possible, in order to be aware of the motifs of the music piece.

Given that this is an expression of how the player feels about the music, it is not necessarily a System 2 process, but is gradually shifted to a System 1 process. Repeat the performance expression in the System 1 process as trial and error until the player's intention is well conveyed. The player repeats the pattern that successfully shares the expression he/she wants to share in the System 2 process to fix the expression. In addition, although System 2 and System 1 repeatedly appear during practice, there will be situations where "System 2 $<$ System 1." This is a time when unconscious performances increase and dramatic improvements in performance expressions occur.

As player's technique improves, he/she gradually discovers new discoveries and desires for additional expression in the piece. As player's techniques improve, he/she can make new discoveries for motifs/notes significance, and grow his/her

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appetite regarding compositional expression. Some of these improvements can be made solely by P^3, while others can only be made with the advice of the instructor. In any case, the final regulation for the competition will be made by repeating such improvements. At this time, the utilization of knowledge increases in the System 1 process in order to challenge a variety of expressions. In addition, even without the System 2 process, the approach to the state known as "the body remembers" and enables various expressions to be challenged.

IV. Discussion Based on Two Minds

A. Overview of Annual Lessons

The following is a summary of the practice sessions described in Section III, contrasted with the duration of the lessons. In order to take lessons, the learner makes practices about one hour per practice. The number of practice sessions is generally two to three times per week, depending on the situation at the time. One to two weeks prior to the competition, practice sessions occurred almost every day.

- 11 months prior to the qualifiers of the competition (C_P): Selection of pieces
  Play a few pages of several music pieces and select the pieces that suit the player's favorite
- Six months prior to C_P post-selection of music pieces: score reading (T_{C1}).
  Basically, the students practice developing techniques in some parts while focusing on the mechanics. It takes about three months to reach the level of playing through the whole piece, and the playing speed is two to four times slower than the specified speed.
- Six to three months prior to C_P: Transition to the expression of musical ideas (T_{C2}).
  ** By this time, the mechanics are 80% complete, so the main focus is on practicing to develop the techniques necessary for compositional expression.
- Three months prior to C_P, completion of the compositional expression:
  Completion of the musical compositional expression · constructing the music image (T_{C3}).
- 1 month prior to $C_P \sim C_P$: final adjustment for the regional qualifying round. (T_{C4}).
- Post C_P to the primary line of the competition: if you pass the qualifying round, practice for the regional finals (T_{C5}).

A total of 25 lessons were given. Each lesson lasted approximately 1.5 hours.

B. The Relation Between the Flow of Playing Perfection and Two Minds

Once a series of experiences had been performed, the second trial for attending the competition may be able to utilize the prior experience to finish the piece at a faster pace. The items from stage 2 (practice) analise(1) to the effort for fluent performance in Figure 2, or $T_{C1} \sim T_{C2}$ in terms of the lesson schedule, are basically affected by the experience. It is possible to reach the stage of mechanical performance as reproducing with midi, through an expreience such as earlier through participating in competitions repeatedly, taking lessons for many years, and so on. These changes are continuous, i.e., the degree of improvement increases monotonically as a function of the number of performances.

However, additional interpretation and deepening of the performance beyond that point may not be successfully achieved by simply repeating the process. In P^3's participation in the competition, the performance around two to one month prior to the competition qualifier (T_{C3}) undergoes a large change every year, which cannot be explained by the passage of time alone. By this time, the mechanical performance is almost complete in a form that is approximately 1.5 times less than the speed at which it is played on the day of the competition, but it is far from sufficient completion, and the so-called "composition expression and understanding." Around the transition from T_{C2} to T_{C3}, there is a significant change in the recognition of musical motifs and a shift to the recognition of larger motifs and the expression of *Dynamik* including expression marks. Other changes in timbre, for instance, from soft to hard sounds, are also observed.

This situation is further analyzed from the perspective of the disparities between the characteristic times of System 2 and System 1. The period of T_{C1} is a practice process in which the System 2 process is dominant. The time scale for practice per phrase is primarily the cognitive band in Newell's Time Scale of Human Action [14], since the phrase itself is not very long. The time span of the cognitive band is about $\sim$10[s]. Given that information is exchanged between the working memory and long-term memory in about 10 seconds of very short chunks, all knowledge is likely to be recognized only as fragments. Therefore, even if one were to predict the next chunk that will appear during the performance of a piece of music, only a few chunks exist which is able to collation, and even if many chunks can make connected collation, only a few percent of the entire piece can be predicted, making it difficult to see the entire piece.

By repeatedly practicing a very short chunk, the body remembers new chunks in the order of ease with regards to memorizing. If a similar chunk had been utilized in the past, it is recognized as a "meme" and the chunk becomes an active meme [15]. At this stage, the chunk is considered an action-level meme. Conversely, even if a chunk exists in long-term memory, if it is never invoked again, the chunk is no longer imitated and becomes an extinct meme, therefore making it inactive. From the above, for a learner like P^3 who cannot engage in constant piano practice, score reading at the competition level will require an enormous amount of time.

However, by the time the T_{C1} period had elapsed, the information per chunk is considerably larger. Therefore, during T_{C2}, chunks of the larger size are available for the cognitive processes in the cognitive band. The number of chunks available for cognitive process, invoked chunks, is getting longer and longer, and their coverage is getting longer. As a result, the number of operations utilizing the working memory and

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TABLE I. PHASE CLASSIFICATION OF KNOWLEDGE/COGNITIVE PROCESSES AND DEGREE OF INFLUENCE

		process		knowledge		environment
Phase	Subphase	System 1	System 2	tacit	explicit	outsider intervention
decide piece	offer candidate	*	*		*	**
	once-over	*	**	*	**	**
	playing trial	**	*	**	**	
	listning	***	*	**	*	*
	select piece	***	*	***	*	*
score reading	fingering		***		***	
	score reading		***		***	
analise(1)	recognize motif		***		***	*
	set enphasis		***		***	*
	find motif of serendipity	***	*	*	***	
expression	mechanic	*	***	**	***	***
	construct image	***	**	**	**	
	transfer expression	**	**	*	***	**
analise(2)	confirm expression	**	***	**	***	***
	confirm image	**	***	***	**	***
	Technic		***		***	***
	performance deepening/serendipity	***	***	*	***	
final stage	fragmentation and reintegration	**	**	**	***	

long-term memory for a unit time will be gradually increased, and the addition of information to the chunks in long-term memory will be accelerated. In simple words, it is thought that the easily accessible active meme will change to behavior-level meme [15]. In this process, the time when a knowledge group is composed of only an appropriate chunk size may be approximately the time toward T_{C3}.

By the time T_{C3} is entered, the number of movements to call chunks from long-term memory is considered to be considerably reduced. As a result, cognitive-motor coordination is conducted more unconsciously. If all the chunk invocation patterns are optimized, almost all the performances will be performed unconsciously by System 1, and an abrupt phase transition from the T_{C2} state will occur. As a result, one should feel at least a dramatic improvement in their ability for good finger movement.

In the case of P^3, the pieces learned in the last three years, including the time of writing this article, were as follows:

- 2 years ago :
  Partita BWV 826, composed by J. S. Bach (score A)
- 1 years ago :
  Allegro Appassionate op.70, composed by Charles Camille Saint-Saëns (score B), Allemande in French Suites BWV 812, composed by J. S. Bach
- now :
  piano sonata op. 14 first movement, composed by Sergei Sergeyevich Prokofiev (score C), Allegro in Italian concert BWV 971, composed by J. S. Bach

Each of them spent about a year memorizing the scores prior to the competition. Despite the difference in the compositional age, compositional structure, and knowledge required, score A received 76 points and score B received 79 points in the final piano competition. This indicates that the learners' performance skills themselves were well-developed, even though they performed different types of music. In simple words, the examples of the experience in Section III can be considered to have a certain universality.

C. The Relation between Knowledge/Cognition Process and Two Minds

Finally, we discuss the relationship between the Two Minds and the knowledge as well as cognitive abilities acquired through a series of piano practice and lessons. Table I exhibits the results of subjective evaluation for each flow subphase in Figure 2. The items are: the process of the Two Minds, the knowledge system utilized (implicit/explicit), and the subjective evaluation of the degree of intervention by others. The higher the number of $*$, the stronger the effect on the item.

At initial glance, one might think that instrumental music performance is a continuous shift from long time-consuming mechanical training by System 2 (inference) to unconsciousness of musical expression including System 1 (intuition). However, in fact, this is not true.

For instance, in the case of the music selection phase, many factors are involved in the decision-making process, including player: 1) preference (System 1), 2) matching with perfor-

mance ability (System 1/2), and 3) matching with the ability to read music (System 2), etc. It depends on the situation at that time which of these factors should be prioritized. In simple terms, if motivation is a given priority, preference is given priority, and if ability is given priority, a little more weight is given to the performance ability or reading ability. This indicates that the process of proficiency in instrumental performance is not determined solely by preference or ability. Conversely, song selection, although often neglected at the initial glance, is the most important phase as it is deeply related to the motivation of the student when he or she begins to practice. In the case of the piano beginner, the instructor often selects pieces at an appropriate level, but in the case of a proficient amateur learner, the selection requirements for the score selection are reduced to some extent. Therefore, the degree of freedom of parameters is high, and the decision-making process involves a mixture of perceptual processes to trigger preference by listening to the sound source, perceptual-cognitive processes to compare with the reading ability by score reading, cognitive-motor processes to consider the performance ability, and processes to coordinate all of these. Therefore, the ability to select appropriate music can be regarded as an important ability.

This also applies to the score selection process. It is easy to assume that a System 2 process takes precedence in *Analise* as well, since it requires a precise analysis of the music. However, various cognitive processes are intricately related as follows: Recognizing the motive and searching for methods to emphasize it (System 2), determination of the expression method that is perceived as effective (System 2/1), new expressions discovered by chance (System 1), and so on. Therefore, not only an orderly musical interpretation but also a balance with the impression is important. In particular, when representing a piece of music, it is necessary to "see the big picture", i.e., the following items must be fulfilled at the same time.

- The player must have a complete understanding of how to perceive the entire piece (System 2).
- The player's natural behavior as if he/she were performing it unconsciously, which should be comfortable for the listener (System 1).

Therefore, it is necessary to understand the process of coordination between System 2 and System 1.

V. Conclusion and Future Works

In this study, based on the MHP/RT cognitive architecture and its companion field study methodology, CCE, we attempted to understand the process of proficiency in music performance by proficient piano players as a brain model based on the coordination of perception, cognition, and movement, as well as the Two Minds.

In Section II, we theoretically explained the development process of the chunk structure that exists in the long-term memory, which is the most important part of the piano playing process – score reading and piano playing mechanics/technics. There is a structure, which consists of many small units of chunks in the long-term memory, and links are attached between chunks through practice. As a result, larger chunks are formed. The study argues that the proficient state refers to this state.

In Section III, we ethnographically described the piano practice and proficiency process with P^3 as an example, aiming at participation in the competition. We exhibited that there are four major components: selecting score (System 1), practice (System 2), *Analise*(System 1/ 2), and the effort for fluent performance (System 1/2).

In Section IV, a series of piano playing exercises and lessons were analyzed from the perspectives of the Two Minds, the knowledge system utilized (implicit/explicit), and the intervention of others. Post the analysis, the relationship between the acquired knowledge and cognitive abilities as well as the Two Minds was examined by incorporating the idea of the active meme. The results suggest that instrumental music performance requires both a complete understanding of how the player perceives the entire piece (System 2) and natural behavior that is comfortable for the listener (System 1), as if the player were playing unconsciously.

As an application, we can consider various educational support measures for performance proficiency by understanding the actual growth process of chunks and the player's proficiency process in more detail based on cognitive architecture. In recent years, there have been increasing opportunities for adults who are not professions of instrumental music performance to enjoy music as a hobby as amateurs. While he/she is not a professional with regards to instrumental performance, one of the elements necessary for proficiency, "motivation to practice" and "support for its maintenance", is left solely to the desire of the learner to play this piece, not to the instructor. In this situation, if learners cannot overcome the difficulties they encounter when practicing instrumental music, they may give up the hobby of instrumental music itself. However, if the instructor can appropriately understand the difficulties that the learner cannot overcome, and can demonstrate to the learner how to increase the possibility of overcoming the difficulties, the withdrawal rate of the learner may be reduced. We believe that this study will contribute to the research from this perspective.

The majority of prior research on the process of proficiency in musical performance has focused on the understanding of cognitive mechanisms for individual perceptual, cognitive, and motor processes. Research on the cognitive mechanisms of individual processes is primarily suitable for understanding proficiency or the process of developing literacy, in terms of how beginners can play music. This study's findings can apply to constructing efficient training methods for the novice learner.

However, learner's playing skill shifts slowly with time, so that it is necessary to improve teaching content and methods based on the learner's proficiency. In case the learner's goal level with regards to attending the competition, is not only the improvement of literacy but also the process of proficiency in the "big picture" of a piece of music. In order to establish such a sophisticated instructional method for individual cases, we

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need a method for analyzing successful/failed cases based on the empirical rules of instruction, and the resulting cognitive model of the learner. In this case, it is necessary to go into the resonance with past performance and appreciation activities, and there are many areas that cannot be elucidated only by the prior cognitive architecture. As one of the solutions to this problem, understanding performance proficiency utilizing a brain model based on the Two Minds is considered to be effective. As a future issue, we believe that further research based on this study will enable, for instance, remote performance instruction of musical pieces at a higher level.

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