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Guzheng Fingering Practice Assistant System Based on Gesture Recognition: Supporting Practice by Providing Feedback

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Abstract. Beginners need a lot of practice to master fingering as a motor skill. However, in the post-lesson practice sessions, beginners often fail to provide internal feedback due to a lack of proper long-term memory, which ultimately leads to high error rates and poor practice results. This paper proposes a system to assist in the practice of Guzheng fingering. By constructing three corresponding student types and feedback implementation scenarios to provide different types of augmented feedback, the system aims to better support beginners in practicing Guzheng fingering on their own. The system employs gesture recognition technology to support the feedback intervention, and positive results were obtained through comparative experiments in which the system's recognition and judgement functions could be used.

Keywords. Augmented feedback, Guzheng Fingering Teaching, Motion capture, Gesture recognition

1. Introduction

Feedback is considered to be the most influential variable affecting the learning and performance of motor skills [1]. Researchers point out that feedback is essential for learning and skill acquisition [2–4]. Without feedback, learners will be restricted in how to judge their progress and how to change their future performance [5]. At present, there are more and more researches and application of feedback in the field of motor skill teaching. For example, in table tennis training, a table tennis virtual teaching system is proposed, which provides real-time feedback to support table tennis practice [6]; Another example is a wearable device called Music-jacket, which can provide real-time tactile feedback, and can be used to help violin beginners practice bow [7]. At the same time, by setting up controlled experiments, researchers found that augmented feedback can bring greater improvement to motor skills than simple training [9]. On the other hand, because it involves the attitude control of various parts of the body, most of these systems use motion capture technology to track human body's motion and obtain relevant objective data. The use of sensors further improves the accuracy of feedback and provides a reference for the realization of system technology.

However, researchers also pointed out that the influence of feedback is not always positive, and different types of feedback may have different influences on learning outcomes in different situations[4,8,10]. For example, in terms of feedback timing, real-

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time feedback can avoid the formation of wrong muscle memory and cognition in the beginning of practice, but it is easy for practitioners, especially novices, to become dependent; delayed feedback can ensure that practitioners can completely retrieve what they have learned before receiving feedback information, and help them remember more learning content [3]. Similarly, the influence of different feedback frequencies on learning outcomes is different. Relevant experiments show that although feedback has positive effects on skill practice, such as motivation, association, guidance, etc., if it is too frequent, the learning effect will be reduced [11]. The guiding hypothesis also points out that additional feedback can help improve learning performance, but it will also affect the formation of inherent feedback and the implementation of corrective work[12]. Currently, most of the systems that provide feedback to support motor skill practice enhance the learning process by providing 100% real-time feedback, and the degree of application of feedback is inadequate.

As one of the traditional Chinese musical instruments, the Guzheng has a history of over 2,500 years. Fingering, as one of the core exercises, not only includes the requirements of hand shape, but also the requirements of the position of the strings, the strength of the strumming and the direction of the strumming, compared to the fingering of the piano and guitar. At the same time, different fingers and different plucking directions correspond to different fingering techniques, making fingering practice difficult, varied and demanding. Practitioners need to do a lot of practice after lessons in order to reach the required standard. However, for beginners, as the learning time is still short, they do not have enough knowledge to judge the results of their actions and produce correct internal feedback, so they are prone to repeatedly practice the wrong movements, resulting in ineffective practice, which eventually leads to low learning efficiency, low self-efficacy and gradual loss of interest in learning.

To address the above issues, this paper proposes a Guzheng Fingering Assisted Practice System (GFAP System) for supporting beginners in practicing Guzheng fingering after lessons. The system captures the practitioner's hand data through Leap motion, identifies the corresponding fingering and determines the student type. Further, feedback implementation scenarios are identified to match the student type and the corresponding feedback entities are produced, thus ensuring the effectiveness of the feedback intervention. The aim is to solve the problem of insufficient feedback for beginners practicing alone and to avoid ineffective practice.

The paper is organized as follows: the next section describes the analysis of users' cognitive activities in the application scenario of the system, clarifies the root of research problems, and draws the core goal of the system. The third chapter focuses on teaching feedback theory and its related application research in the field of motor skills. The fourth chapter introduces the Guzheng fingering assistant practice system, including system feedback model, student type matching, feedback realization and technical support. The fifth chapter introduces the usability experiment of the system function and the experimental results. The sixth chapter discusses the experimental results, and describes the challenges faced by the research and future work from the final goal.

2. Background-Cognitive activity analysis

Guzheng fingering, as one of the core learning elements in the beginner stage of Guzheng, is not only related to the tone and volume of the performance, but also closely related to the musical expression and quality of performance in the intermediate and advanced stages. It includes the requirements for strength, position, corresponding fingers, playing direction, etc. It is difficult for the beginner Guzheng player and often leads to a high error rate and eventually a reduced sense of self-efficacy and loss of interest in learning. There are two main parts of Guzheng practice, one is classroom practice and the other is after-class practice. After-class practice is more difficult because there is no guidance from the Guzheng teacher. At the same time, classroom practice time is limited and the improvement of fingering often depends on after-class practice. Therefore, we use the after-class practice stage as the application scenario for our study.

Educational psychology believes that motor skills are composed of two parts, including rules describing how to perform actions and actual muscle movements. At the same time, it is emphasized that motor skills are not only related to muscles, but also related to sensory perception and brain cognitive process [13]. When performing cognitive tasks, working memory is a brain memory system that provides information needed for temporary storage and operation [14]. Cognitive psychology divides working memory into declarative working memory and procedural working memory. The former supports the storage and use of facts and events, while the latter is related to motor skills, cognitive skills and cognitive strategies [15]. It can be understood that declarative working memory supports the provision of corresponding rules while procedural working memory is responsible for supporting the corresponding muscle activities in performing motor skill-related activities. On the other hand, although declarative and procedural working memory are responsible for different contents, they operate according to a similar mechanism [16]. Researchers say that both of them support the execution of corresponding tasks by activating the corresponding memory sets in long-term memory.

Based on cognitivism [17], we analyzed the cognitive processes of Guzheng players during after-class practice, aiming to elucidate the underlying causes of the high error rate and poor practice results of beginners in after-class practice. As shown in Figure 1, during practice, Guzheng players generate internal feedback by comparing the perceptually acquired information about the behavioral outcome with the working memory formed by activating the corresponding long-term memory, thus supporting self-judgement and error correction of the behavioral outcome. However, for beginners of the Guzheng, their long-term memory is inadequate due to the short learning period, including the knowledge of the rules associated with the movement and the muscle memory for executing the movement. As a result, it is difficult to perform quick and correct cognitive processing to form a working memory that can provide adequate and accurate internal feedback for themselves. In addition, there is no augmented feedback from the outside world during the post-session practice sessions, which results in beginners being unable to judge the outcome of their actions when practicing alone. This ultimately results in an insignificant reduction in error rate and a reduced sense of self-efficacy after practice. Thus, for the beginner Guzheng player, internal feedback is one of the main causes of learning problems at the beginner stage, and insufficient correct long-term memory is the root cause of these learning problems. On this basis, the core objective of the proposed GFAP system is further clarified: to solve the problem of internal feedback inherent to beginners and to help them build up correct long-term memory.

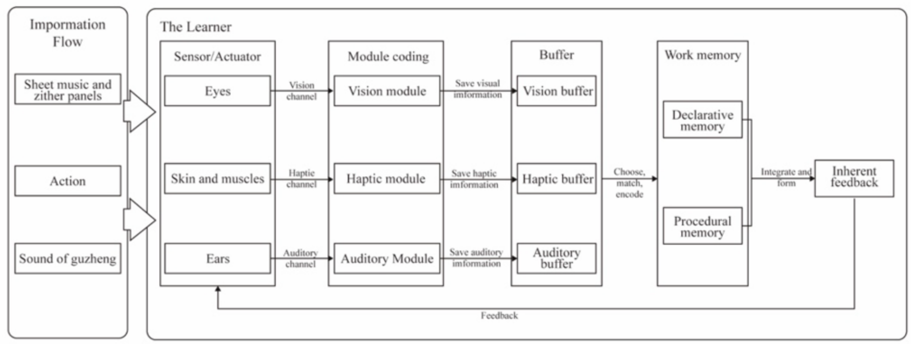

Figure 1. Cognitive Model of Guzheng Practitioners' Alone Practice Moment.

3. Related Work

In the field of motor skill teaching, feedback refers to information received by learners during or after exercise [13], aiming at improving learning [18]. At present, feedback intervention, as an important teaching intervention means, has been widely used in the auxiliary teaching system of motor skill learning or practice. For example, table tennis assistant teaching system which provides real-time feedback [6,19]; Support the practice of golf putt action through timely feedback [20]. At the same time, feedback is not only applied in the auxiliary teaching system of sports competitions, but also widely used in the auxiliary system of musical instrument teaching. VEMUS is a virtual European music school project, in which researchers developed a music teaching system for wind instruments [21]. The system provides appropriate structural comments according to the instruments played, and gives real-time feedback in the form of hearing and vision. In this research, the corresponding feedback information is presented mainly based on the visualization of music scores, so as to support the system to evaluate homework exercises instead of teachers. Carlos Torres Fernandez et al. proposed a piano practice program using virtual characters [22]. In this program, augmented reality is used to help practitioners to train piano, and virtual characters are used to provide real-time visual feedback. It also has the same application in the auxiliary system of body posture control in the process of musical instrument playing. For example, Music Jacket [7], which provides real-time tactile feedback to support violin bowing practice; An integrated vibration tactile system which provides real-time tactile feedback, taking violin teaching as an example [23]; An auxiliary system for supporting piano posture practice through 3D visual auxiliary feedback [24]; And bilateral data gloves providing real-time feedback to support guitar practice [25]. Although these systems apply feedback intervention to motor skill teaching, most of them take real-time feedback as the main form of feedback information presentation. Studies have pointed out that when providing high-intensity feedback, students will become passive and dependent on the feedback, thus failing to achieve the expected learning effect [26].

Researchers generally believe that feedback has a positive impact on learning and motor skills [13,27]. Related experiments also demonstrate this view. For example, through the control experiment, it is found that positive comparative feedback can improve the expressive force of children basketball players' free throws [28]; Providing timely feedback has a positive impact on beginners to learn piano and master related techniques [29]. However, researchers say that feedback is not always positive [10,26], the types of feedback and the scenarios provided may have different effects on learning [30], and the conditions for the implementation and success of feedback are complex and multifaceted [27]. Relevant empirical studies have also demonstrated these views. For example, feedback frequency. In the experiments related to the influence on the teaching effect of dance motor skills, it is found that compared with complete feedback and no feedback, reduced feedback has the best teaching effect [31]. Facing the difficulty of different teaching contents, the best feedback frequency is also different. The experiment shows that for children, providing 33% feedback frequency in low-difficulty teaching content can achieve the best learning effect, while providing 100% feedback frequency in high-difficulty teaching content can achieve better learning effect [32]. As one of the most influential viewpoints in motor skill learning [10], the Guidance Hypothesis holds that if additional feedback is presented too frequently, it will make the practitioner become dependent, and when it is not presented, the individual's achievement will drop [12]. In terms of feedback timing, it is more conducive to learning for practitioners to get feedback when the self-practice effect is good [33]. Compared with error-correcting feedback, explanatory feedback can promote beginners to have a deeper understanding in learning [2]. Positive feedback can promote learning more than negative feedback [18,34]. Therefore, it can be found that there are some shortcomings in the research and application of feedback in most current motor skill-assisted teaching systems. Although there are no uniform and clear rules on the specific conditions for effective feedback in motor skill teaching. But it is clear that a single, 100% real-time feedback form is definitely not the best feedback way in motor skill teaching.

In addition, the researcher also emphasized the central position of students in the feedback process [27]. On the one hand, traditional teachers' high-intensity feedback will make students become passive and rely on feedback [35]. The research emphasizes the importance of feedback to students' agency and participation, and activating students' thinking and information retrieval in learning can improve learning results [26,36]. On the other hand, students' individual differences, including their motivation, prior knowledge and self-efficacy, will all affect the effect of feedback intervention [27]. Therefore, in this study, combined with the core objectives of the system mentioned above, on the basis of providing augmented feedback to make up for the lack of inherent feedback for beginners, three application scenarios are divided according to the learning situation dimension, so as to provide feedback entities that are in line with students' current learning situation and further improve the effectiveness of feedback intervention.

On the other hand, motion capture technology is widely used in the field of motor skills [37]. In the above-mentioned musical instrument posture teaching assistant system, motion capture technology is also selected to capture the relevant physical data of the practitioner in real time as a feedback basis. This provides a technical reference for the implementation of GFAP System technology. Combined with the fact that Guzheng fingering is a motor skill that focuses on hand movements, gesture recognition technology is considered to capture the hand data of Guzheng players in order to provide systematic technical support.

4. The GFAP System

Given the motivation for this study and the application of the GFAP system in a practical teaching scenario as a source of additional feedback, the requirements for this system were (i) Real-time operation; (ii) Support for data collection and gesture recognition from the hand; (iii) Portability; and (iv) No interference with hand movement. These four requirements led us to select Leap motion as the hardware device for the sensor part of the system. the recognition position of Leap motion is shown in Figure 2. Part of the software was written in C# in unity.

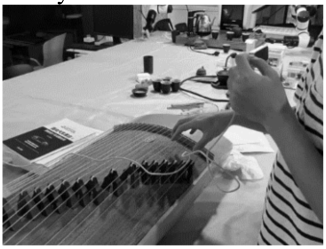

Figure 2. Schematic diagram of the placement of Leap motion in GFAP System.

Through the above analysis, it is clear that GFAP System can achieve the goal of teaching assistance at two levels by providing feedback information that conforms to the learners' learning situation: (i) Providing augmented feedback to make up for the lack of feedback in the beginner stage; (ii) Ensure that feedback intervention always has a positive impact. Aiming at the goal (i), the system performs player gesture recognition, corresponding data capture and data analysis based on Leap motion, so as to obtain behavior result information and support providing augmented feedback; Aiming at the goal (ii), this study constructs three implementation scenarios. At the same time, to determine the types of students corresponding to different scenarios, the purpose is to determine the current scenarios and provide appropriate feedback entities through data mining and learning situation analysis, so as to ensure the positive impact of feedback intervention.

Therefore, GFAP System needs data acquisition, data analysis and feedback presentation to realize feedback intervention. The system flow is shown in Figure 3. First, the player's hand data is acquired by Leap motion in the data sensing layer and transmitted to the data analysis layer. Call the corresponding data of fingering index database and standard database, judge whether the corresponding index of the current playing gesture is correct, and calculate the corresponding data to determine the type of students. The application scenario is determined based on student type matching, and the feedback entity is generated, and finally presented on the interactive interface.

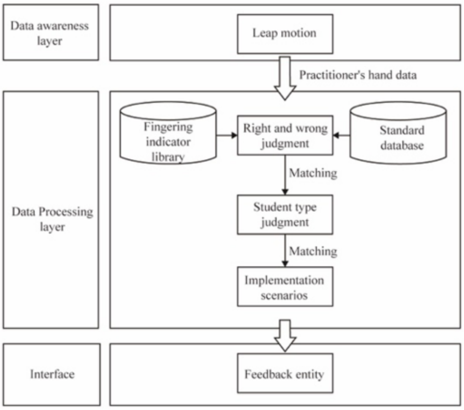

Figure 3. GFAP System Workflow Framework.

4.1. The feedback Model

The feedback model of GFAP System is based on the feedback model proposed by Hattie and Timperley [30], which aims to build different types of feedback entities to make up for the lack of inherent feedback among beginners and improve the effectiveness of feedback intervention. The feedback model proposed by Hattie and Timperley points out that feedback intervention needs to answer three questions: (i) Where am I going? (ii) How am I going? (iii) Where to next? Based on these three problems, the hierarchical structure of GFAP System feedback model is shown in Figure 4, which includes: (i) The target level: includes a database of fingering indices and practice phases and is created to help practitioners identify success criteria for practice; (ii) The difference level: includes a database of standards and is designed to help practitioners identify variations from the standards; (iii) The implementation level: includes types of feedback and different implementation scenarios and is designed to assist with fingering practice as well as promote understanding of fingering rules.

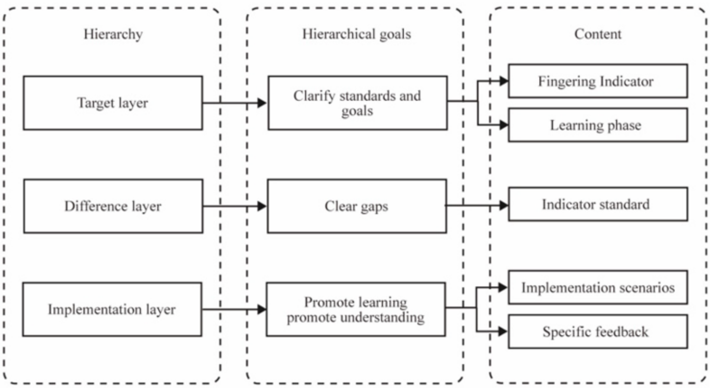

Figure 4. Feedback model hierarchy of GFAP System.

4.1.1. The target layer

In response to question 1 "Where am I going?", which refers to the need to help practitioners clarify the objectives of the exercise, including what the correct movements are and what the movement requirements are, when providing feedback. Therefore, we have created a database of target-level Guzheng fingering indicators to help practitioners clarify the correct fingering requirements. At the same time, the different stages of fingering practice are differentiated, and the objectives of each stage are established in order to refine the practice.

Through literature research, classroom observation and expert interviews, the requirements of Guzheng fingering are investigated and analyzed, and the Guzheng fingering is indexed according to certain classification criteria to construct a Guzheng fingering index database.

Firstly, a classification of Guzheng fingering. At the primary stage, Guzheng fingering can be divided into single fingering, i.e. fingering with a single finger, such as fingering *Gou, Mo, Tuo*; combined fingering, i.e. combining two or more single fingering, such as fingering *Dacuo*, which is composed of fingering *Gou* and *Tuo*; and two-handed fingering, i.e. fingering played by the right hand and left hand, such as *Shanghuayin*. all three types of fingering consist of three steps, namely (i) Preparation; (ii) Touching the strings; (iii) Plucking the strings. At the same time, the standard requirements for the preparation step are the same in different fingering styles. On this basis, we define the Guzheng gestures into two categories according to the movement state of the hands: (i) Non-playing gestures: refers to the static gestures in preparation for Guzheng playing, specifically the *Ready hand*; (ii) Playing gestures: refers to the fingering movements named in the textbook, such as *Gou*, *Dacuo* and *Shanghuayin*.

Secondly, the fingering requirements of the Guzheng are analyzed in terms of hand parts or processes, and the categories of indicators corresponding to the defined gestures are determined. The non-playing gesture is a static gesture and is therefore divided into: (i) Wrist; (ii) Fingers; and (ii) Palm. The playing gesture is a dynamic gesture, where the requirements of the parts change under a constantly changing movement. Therefore, the playing process is used as a marker to construct the indicator categories, which can be divided into five dimensions: (i) Corresponding playing finger; (ii) The direction of touch; (iii) Point of force; (iv) Plucking force; (v) Plucking direction.

Thirdly, different stages of practice and their corresponding indicators are constructed. In classroom observations and user interviews, the Guzheng teacher will suggest different learning objectives according to the learners' progress and ability. For example, a complete beginner is only required to be able to judge the playing fingers as well as the direction of touching the strings and the direction of plucking, while the point of power and the strength of power are not required too much until the teacher considers that the student's current ability is sufficient to master these two points. A Guzheng teacher who has been teaching for six years says. This reduces the difficulty of learning and allows beginners to master the appropriate fingering more quickly. For this reason, we have divided the fingering indicators of the Guzheng into two stages, namely the Beginner Stage and the Advanced Stage. The aim of practice in the Beginner Stage is to correctly grasp the requirements of the *Ready hand*, to judge the corresponding fingers and playing direction of the Guzheng fingering and to ensure that the strings are touched in the correct direction. The objective of the Advanced Stage is to build on the requirements of the Elementary Stage, to master the power point and power strength and to play with a certain intonation. With the support of Guzheng experts, the targets are set and divided according to the learning objectives of the different stages. Taking *Ready hand* and *Gou* as examples, the corresponding indicators for these two stages are shown in Table 1.

Table 1. Corresponding indicators for the *Ready hand* and *Gou*

stage	gesture type	gesture	indicator
Beginner Stage	Non-playing	Ready hand	Whether the wrists are flush
			Whether the five fingers are slightly bent
			Whether the palm is half clenched
	Play	Gou	Did you play with your middle finger
			Whether the distal knuckles of the middle finger touch the chord parallel
			Whether the playing direction is inward
Advanced Stage	Non-playing	Ready hand	Whether the wrists are flush
			Whether the five fingers are slightly bent
			Whether the palm is half clenched
	Play	Gou	Did you play with your middle finger
			Whether the distal knuckles of the middle finger touch the chord parallel
			Whether to force the first knuckle
			Whether the plucking force is in place
			Whether the playing direction is inward

4.1.2. The difference layer

In response to question 2 "How am I going?" , the aim is to help practitioners identify current gaps with the standards by providing feedback. Therefore, in the gap layer, gaps between practitioners and standards are identified by constructing a database of standards.

Having identified what is required to determine the gap, i.e. the hand gestures and indicators in the fingering indicator library, the standard data corresponding to each indicator is further determined, thus supporting the acquisition of practitioner behavioral results and related data and clarifying the "gap". Firstly, according to the data types provided by Leap motion and the set indicator requirements, each indicator corresponds to the collected hand data.

As shown in Figure 5, take the palm position as the coordinate origin, and establish a spatial rectangular coordinate system. The data involved include: (i) The vertical component of the palm normal vector $\vec{P}$, used to represent the height of the wrist; (ii) The degree of palm depression G, used to indicate the state of the palm of the hand; (iii) Distal knuckle tip velocity - TipVelocity, used to indicate the state of force; (iv) The distance M(x) from the distal knuckle to the center of the palm, which is used to indicate the movement state and direction of the finger x; (v) The angle between the distal knuckle vector and the coordinate axis is used to represent the state of the distal knuckle. Among them, due to the different direction of force, the big finger is the angle between the distal knuckle vector and the x-axis $\angle\mu$, and the other four fingers are the angle between the distal knuckle vector and the z-axis, respectively $\angle\alpha$, $\angle\theta$, $\angle\beta$, $\angle\gamma$.

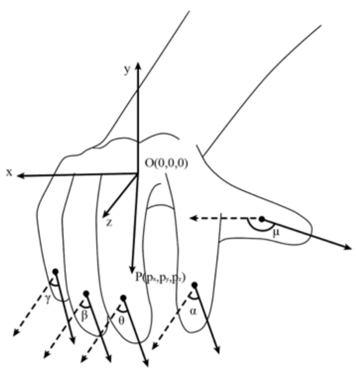

Figure 5. GFAP System gesture recognition coordinate system and related data

In order to obtain the standard threshold value corresponding to each index, we collect the data corresponding to each index of Guzheng practitioners. During the collection process, the Guzheng master is required to play the defined gestures for 40 times, in which the gesture of *Ready hand* is kept for 40 seconds. Through noise reduction and filtering of the collected data, the average variation range is calculated to determine the standard interval of this index. We have collected the data corresponding to the same index of beginners and proficiency, taking the palm depression value G of *Ready hand* as an example. The data displacement diagram of beginners and proficiency after 30s is shown in Figure 6. As can be seen from the figure, there is a certain difference in the range of numerical period change of hand data between beginners and proficient Guzheng players, and the range of numerical change of beginners is larger; Compared with beginners of Guzheng, the corresponding data of those skilled in Guzheng are more regular and stable. Considering the high error rate of beginners, and the wide range of changes compared with those of skilled people due to the low standardization of movements, if the threshold range is set too small, the the number of wrong results will be too more, which is not conducive to beginners' fingering learning. Therefore, under the guidance of Guzheng experts, according to the two-stage practice objectives, the range of threshold changes were reasonably expanded. Among them, the data range of Guzheng teachers is expanded by 10% in Beginner Stage and 5% in the Advanced Stage to build the final standard database. It should be emphasized that the standard database contains data types and data standard thresholds corresponding to indicators. As shown in Table 2, it is the standard data value of the advanced stage of the gesture *Ready hand.*

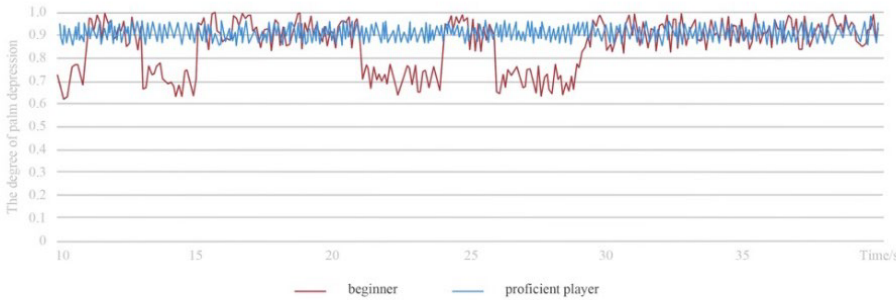

Figure 6. Comparison of palm depression values of *Ready hand* gesture of beginner and proficient player.

Table 2. Standard data value of advanced stage of *Ready hand.*

Indicators	Type of date	Threshold range
Whether the wrists are flush	Palm normal vector vertical component	-8.5~9.8
Whether the five fingers are slightly bent	The angle between the distal phalanx of the thumb and the x-axis	105~130
	The angle between the distal phalanx of the index finger and the z-axis	65~90
	The angle between the distal phalanx of the middle finger and the z-axis	70~95
	The angle between the distal phalanx of the ring finger and the z-axis	65~85
	The angle between the distal phalanx of the little finger and the z-axis	55~85
Whether the palm is half clenched	Palm sunken degree	0.75~0.96

4.1.3. Implementation layer

The third question, 'What next', aims to provide information on behavioral outcomes through the generation of feedback entities to help Guzheng beginners improve their performance as well as understand the key points of fingering and obtain positive learning outcomes. Therefore, based on the types of feedback summarized by Panadero, E et al. a library of feedback entities was developed and implementation scenarios for different types of feedback were defined. based on a categorical analysis of 14 feedback models, Panadero, E et al. sorted out and differentiated the different types of feedback in terms of function, source, content and presentation [23]. It provides a comprehensive summary of the current types of feedback. Among them, function and source can be used to identify feedback implementation scenarios and judgement data, while content and presentation can be used to identify specific types of feedback for feedback entities.

Based on these four aspects, a feedback entity library for the GFAP system was constructed.

As for the feedback function, it includes three sub-types: (i) Learning and performance, which refers to providing feedback to improve the performance level of practitioners' related learning content; (ii) Motivation refers to stimulating students' learning motivation through feedback information to obtain better learning results; (iii) Self-regulation ability refers to the ability to improve students' self-regulation, including cognitive processing of knowledge. In this study, improving the fingering performance level of zither beginners is the most basic goal of the system. Combining these three functional subtypes, three implementation scenarios of feedback entities are divided. The three implementation scenarios represent the gradual improvement of students' skill level and cognitive ability of knowledge, including:

- Scenario 1: Improve performance level and stimulate learning;
- Scenario 2: Improve performance level and self-regulation ability;
- Scenario 3: Improve performance level, stimulate learning and self-regulation ability

For the feedback source, it refers to who provided the feedback entity. It can be divided into: (i) Teachers or systems; (ii) Student self; (iii) Companions. As mentioned above, students' agency and participation in feedback can promote their understanding of knowledge and achieve better learning results. On the other hand, for beginners, before they have formed correct and stable long-term memory, it is easy to make wrong actions because of unclear memory. Once they have formed wrong habits, their learning costs will increase. Therefore, the agent of GFAP System is set to change from the system to the students themselves according to the students' performance. From this transformation process, there is more room for Guzheng practitioners to process and understand knowledge, that is, to promote students' self-regulation ability. Therefore, corresponding to the above three implementation scenarios, scenario 1 is the main agent of the system, and scenarios 2 and 3 are the main agents of students.

Furthermore, according to three implementation scenarios, the specific content of the generated feedback entity is set. It includes the content type and statement type of feedback. The content of feedback, which includes four sub-categories: (i) Verification, that is, the right and wrong dichotomy of the corresponding content; (ii) Valence: it refers to positive or negative feedback; (iii) Load: that is, the amount of information presented by feedback; (iv) Specific feedback content. The statement of feedback also includes four subcategories: (i) The timing of feedback; (ii) The frequency of feedback; (iii) Adaptive or non-adaptive; (iv) Form of presentation. Combining the application scenarios of Guzheng fingering and the effects of different types of feedback on different scenarios in related research, for example, positive feedback can promote students' learning motivation compared with negative feedback [18,34], instant feedback can avoid the formation of wrong practice habits in the early stage [3], but it is easy to cause dependence [10], and delayed feedback can promote students' comprehensive processing of knowledge [3]. We set the specific forms of feedback content subcategories and presentation subcategories, and divide them into different application scenarios according to the feedback functions of each subcategory, as shown in Table 3.

Table 3. GFAP System feedback entity library

Implementation scenario	Feedback category	Details
Scenario 1	Content	The result of gestures and indicators; Positive feedback; Direct feedback;
	Presentation	One-time 100% real-time feedback; Visual presentation;
Scenario 2	Content	The result of gestures; Positive and Negative feedback; True and false comparison;
	Presentation	Single or continuous performance broadband feedback; Visual and hearing presentation;
Scenario 3	Content	The result of gestures; Positive feedback; Data trend graph;
	Presentation	Single performance broadband feedback; Visual and hearing presentation;

4.2. Student Types and Matching

In the last chapter, the GFAP System feedback model is constructed, which includes three levels, namely, the target level of "Where am I going", the difference level of "How am I going" and the implementation level of "Where to next". It also distinguishes three implementation scenarios of feedback implementation and the types of corresponding feedback entities. In this section, we identify the student types corresponding to each implementation scenario, with the aim of supporting the student types identified after data capture calculations to match the implementation scenarios to provide the appropriate feedback entity. The feedback function of the three implementation scenarios is differentiated by the need to stimulate learning and to promote self-regulation. The specific application scenarios that require motivational learning and promote self-regulation are analyzed. Where a Guzheng practitioner has a low sense of achievement as a result of poor learning, as evidenced by a high error rate, motivation is required to stimulate learning. In cases where the practitioner has built up a certain level of knowledge, it is possible to reduce the amount of supplementary feedback and the level of detail of the feedback, i.e. to shift the agency from the system to the student, in order to provide the practitioner with the space to perceive and adjust their movements on their own. Therefore, the key point in identifying different implementation scenarios is the student's current level of performance and performance.

For the performance level, it is expressed by the correct rate of gestures or indicators. It can be calculated by Eqs. (1) and (2), where $R_{i(i)}$ is the correct rate of index i; $N_{i(i)}$ is the cumulative correct times of index I in a certain period of practice; $N_{all(i)}$ refers to the total number of times of indicator I in a certain period of practice; $R_{g(p)}$ is the correct rate of gesture p; $N_{g(p)}$ is the cumulative correct times of gesture p in a certain period of practice; $N_{all(p)}$ is the total number of times of gesture p in a certain period of practice. If the correct rate of this classmate's gestures or indicators is lower than 50%, it means that the performance level of this classmate's gestures or indicators is low, which is likely to lead to a low sense of achievement in learning, so it is necessary to provide feedback and incentive exercises. Otherwise, it is not needed.

$$R_{i(i)} = N_{i(i)} / N_{all(i)} * 100\% \tag{1}$$

$$R_{g(p)} = N_{p(p)} / N_{all(p)} * 100\% \tag{2}$$

For performance, we use the correct frequency of gestures or indicators. This data is developed based on the response rate of precision teaching theory [38]. The response rate refers to the number of times students respond to behaviors per unit time [39]. In this study, the response rate is the correct number of gestures or indicators per unit time, which can be obtained from Eqs. (3) and (4). Where $F_{(i)}$ is the correct frequency of index i; $N_{t(i)}$ is the correct number of times of index i in unit time; $F_{g(p)}$ is the correct frequency of gesture p; $N_{t(p)}$ is the correct number of times of gesture p in unit time; T stands for unit time. If the correct frequency is higher than 50%, it is defined that the student has mastered some relevant knowledge, and can act as the main agent of feedback, and the system will provide augmented feedback to promote the cultivation of his self-regulation ability. On the contrary, the system is the main agent to avoid its cognitive deficiency and wrong practice.

$$F_{i(i)} = N_{t(i)} / T * 100\% \tag{3}$$

$$F_{g(p)} = N_{t(p)} / T * 100\% \tag{4}$$

According to the values of correct rate and correct frequency, three types of students are divided to match three feedback implementation scenarios, as shown in Table 4. It should be noted that the student type refers to the student type corresponding to a certain gesture or specific indicator in the learning stage, so as to match the feedback entity that needs to be generated by the gesture or indicator.

Table 4. Types of students and their matching implementation scenarios.

Student type	Performance Level	Performance	Implementation Scenarios
Type 1	R<50%	F<50%	Scenario 1
Type 2	50%≤R<100%	50%≤F<100%	Scenario 2
Type 3	R<50%	50%≤F<100%	Scenario 3

4.3. Technical Support

After the corresponding feedback implementation scene and student types are constructed, it is necessary to capture the hand data of Guzheng practitioners through gesture recognition technology to determine the current student types. The gesture recognition process is shown in Figure 7. First, the hands data of the exerciser are collected by Leap motion. After data collection and filtering, the gesture recognition is carried out by decision tree classification according to the data change characteristics, as shown in Figure 8, and the current specific gesture of the player is determined.

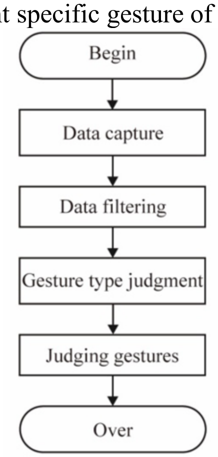

Figure 7. Gesture recognition process

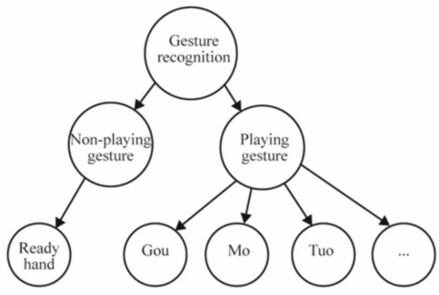

Figure 8. Gesture type and specific gesture judgment

Further, according to the recognition result, the current gesture is judged to be right or wrong, and the corresponding data value is calculated to determine the student model. The specific steps include: (i) Based on the recognition result of the gesture recognition module, the index of the corresponding gesture is called in the index library according to the practice stage, which is used as the target of right and wrong judgment; (ii) Calling the data type and standard data threshold corresponding to the index of the current practice stage in the standard database, wherein the data type is used to determine that Leap motion needs to acquire the real-time data type of the current practitioner, and the standard data threshold is used for subsequent right and wrong judgment; (iii) Comparing the captured data with the threshold value of standard data, and judging whether the index is right or wrong; (iv) Judging whether the gesture is right or wrong based on the right or wrong indicators; when all indicators corresponding to the gesture are correct, the gesture is judged to be correct; otherwise, the gesture is judged to be wrong; (v) Calculate the corresponding data value according to the formula to determine the current student type matching feedback implementation scenario and generate feedback entities.

5. The GFAP System

In this study, the technical support component was experimented with accordingly, i.e. the accuracy of gesture recognition and right/wrong judgement, in order to verify the usability of the system functionality.

5.1. Methods

5.1.1. Participants

Two participants, an expert and a beginner, were recruited for the experiment. The expert guzheng player was a guzheng teacher who had graduated from a conservatory with a degree in guzheng and had 15 years of guzheng learning experience and 5 years of guzheng teaching experience; the beginner guzheng player had just completed 5 hours of guzheng lessons and had not taken any other instrument training. Both were right-handed. Prior to the start of the experiment, the participants were given a detailed explanation of the purpose of the study, the content of the experiment, the criteria for inclusion of personnel and the potential risks.

In addition, a Guzheng teacher with 13 years' learning and 6 years' teaching experience was invited. After the experiment, the playing gestures and indicators of the two participants were manually identified and judged.

5.1.2. Procedure

A comparative experiment was used to verify the effectiveness of the system's recognition and judgement functions. On this basis, the experimental data were divided into four groups: group a was the data of the system's judgement of the behavioral results of beginners; group b was the data of the guzheng teacher's judgement of the behavioral results of beginners; group c was the data of the system's judgement of the behavioral results of proficients; and group d was the data of the guzheng teacher's judgement of the behavioral results of proficients.

The experimental procedure is shown in Figure 9. The four gestures *Ready hand*, *Gou*, *Mo* and *Tuo* were selected for the experiment according to the learning progress of the beginners. Proficient and beginners were tested in a classroom in the same environment. The two testers played the corresponding fingering gestures without the help of feedback and other distractions from the system. The two testers were asked to perform these four gestures 40 times in the working state of the system. The non-playing gestures, i.e. *Ready hand*, were held in motion on cue and each movement lasted 2 seconds; the playing gestures *Gou, Mo* and *Tuo* were considered as one time from moving the fingers on cue to returning to the prepared hand shape. The whole experiment was recorded and made available to the guzheng teacher for gesture recognition and index judgement. To avoid the influence of artificial impressions and habitual thinking of continuous movements on the judgement results. The video of the performance process was segmented in 'times' and then the segmented videos of the two testers were disrupted and provided to the guzheng teacher for gesture recognition and the corresponding index judgement of right and wrong. Finally, the four sets of recognition and judgement results were compared.

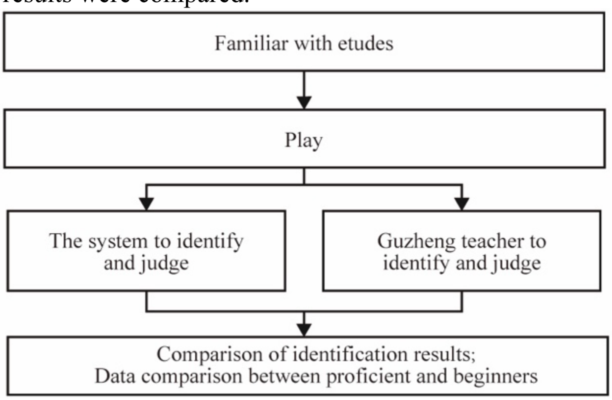

Figure 9. Experimental flow of system functional usability

5.1.3. Data analysis

According to the usability of gesture recognition and right and wrong judgment, after the experiment, four groups of correctly recognized total numbers corresponding to each gesture and the total number of correctly judged indexes of each index are counted. The average value is calculated, and the difference between the two groups of samples is compared by using single sample T test, in which, in the usability verification of gesture recognition function, the completely correct average times are taken as the overall average; In the usability verification of the index true-false judgment function, the data of Group b and Group d are taken as the overall average. It should be noted that, considering that the tester needs a certain time to establish stable hand movements, the 10th to 40th data are selected for analysis.

5.2. Results

The availability of gesture recognition function is shown in Table 5. The average number of gestures correctly recognized by the system is 29.25 for Group a, 29.75 for Group c, 29.75 for Group b and 30 for Guzheng teachers. The P values of the three groups of a, b, c are all greater than 0.05, and there is no significant difference compared with the set overall average. It shows that the gesture recognition function is available, which can satisfy the system's fingering recognition.

Table 5. System and Guzheng teacher gesture recognition average and single-sample t-test results

Group	The average number of correct gesture recognition	recognition accuracy	standard deviation	t	p
a	29.25	96.5%	0.957	-1.567	0.215
b	29.75	99.17%	0.500	-1.000	0.391
c	29.75	99.17%	0.500	-1.000	0.391
d	30	100%	0.000	Null	Null

The availability of the function of judging whether the index is true or false is shown in Table 6. In the single sample T-test analysis, because the beginners themselves have a high error rate when playing, the data result of Group b, that is, the result of Guzheng teacher's right or wrong judgment on beginners' indicators, is taken as the known overall average. For the sake of similarity, the judgment results of the skilled players' playing indexes are compared with the judgment results of Guzheng teachers as the known overall average. Through the single sample T-test, it is found that the P-value of the system's right and wrong judgment results for beginners and proficiency indicators is greater than 0.05, which is not significantly different from that of Guzheng teachers. Therefore, it can satisfy the research system's function of judging whether the fingering index is right or wrong.

Table 6. The system and the Guzheng teacher judge the average number of correct indicators and the single-sample t-test results

Group	The average number of correct gesture recognition	Judgment accuracy	standard deviation	t	p
a	18.11	60.37%	5.860	-1.606	0.215
b	20.33	67.77%	Null	Null	Null
c	29.61	98.70%	0.850	0.006	0.996
d	29.89	99.63	Null	Null	Null

On the other hand, according to the data, we find that the recognition accuracy and judgment accuracy of the system for the same tester are lower than those of Guzheng teacher, regardless of gesture recognition function or index judgment function. This may be due to the fact that the threshold range of the corresponding data is set slightly smaller in gesture recognition and index judgment, which leads to the stricter system judgment rules compared with the artificial ones. On the other hand, the hand size difference of each player may also lead to the reduction of the recognition accuracy and judgment accuracy of the system.

6. Discuss

The experimental results of system usability show that the gesture recognition function and the right and wrong judgment function of GFAP System are available, which can support the gesture recognition and data capture of Guzheng beginners, and the judgment of corresponding gestures and indicators.

However, through the experimental data, we found that the accuracy of the system is lower than that of Guzheng teacher's manual identification and judgment, both in recognition accuracy and in judgment accuracy. This may be due to the fact that the recognition angle of Leap motion may be blocked when the player's hand moves, resulting in a decrease in the accuracy of gesture recognition. Marin, G., et al. proposed a gesture recognition algorithm combining Kinect and Leap motion, and verified its high recognition effectiveness through experiments [40]. In view of this, we consider adding other gesture recognition devices, such as Kinect, or adding other angle cameras to make up for the occlusion problem caused by Leap motion's single angle in optimizing the system hardware devices. On the other hand, judging whether the index is right or wrong may be due to the small threshold setting range and the strictness compared with manual judgment, which leads to the lower judgment accuracy than that of Guzheng teacher. At the same time, it is considered that there may be some errors in setting the threshold range due to different bone sizes of human hands. In view of this, next, we will collect the hand-related data of many Guzheng masters, further improve the threshold setting range, and improve the accuracy of judgment

As for the effectiveness of the system, although the theories of educational psychology and motor skills teaching have general principles of adaptability, the transferability of the teaching effect needs further verification. Therefore, instructional effectiveness experiments are needed to verify the effectiveness of the system's feedback. A comparative experiment on student playing accuracy per unit of learning time is planned to verify whether the system is effective in improving beginners' fingering performance, and a delay test to verify whether the system promotes students' self-learning regulation. Also, the perceived usability and perceived usefulness of the system will be verified through a technology acceptance questionnaire..

Also, in terms of improving the effectiveness of motor skill learning. Researchers have noted that self-controlled practice conditions are generally regarded as a powerful teaching method for promoting more active learner participation and increasing motivation [34]. Therefore, in future research, we plan to further increase the centrality of students in the GFAP system by considering beginners to decide on feedback thresholds, feedback content, and whether to present feedback. Also in terms of student type, we plan to construct learner models in terms of more dimensions such as personality traits, learning styles and cognitive levels in order to improve adaptive personalized feedback interventions and promote the positive effects of feedback on Guzheng fingering learning.

7. Conclusion

This study proposes a Guzheng Fingering Assistance Practice System (GFAP) to support beginners in practicing Guzheng fingering on their own. the GFAP system has two functions: (i) to obtain data from the player; and (ii) to provide appropriate enhanced feedback.

Future work will begin with experiments on the effectiveness of the system's feedback intervention, including post-practice testing of fingering performance levels and skill retention. It is also planned to validate the perceived ease of use and perceived usefulness of the system from a user experience perspective. The system's recognition and judgement accuracy will also be optimized by increasing the number of gesture recognition devices and standard data samples to improve the accuracy of the gesture recognition and indicator positive and negative judgement functions. It is also planned to increase the level of adaptive personalization of feedback by providing students with the ability to self-control whether or not to implement feedback, and by adding multi-dimensional student types such as student personality traits, motivation and cognitive level, thus enhancing the centrality of students in the system.

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