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Effect of Humidity on the Vibrating Membrane of the Python Skin and Eco-friendly Materials Imitation Skin on Traditional Chinese Musical Instrument – Leiqin

Zhang Zixue, Yeoh, Joanne Pei Sze and Camellia Siti Maya Dato' Mohamed Razali
Music Department , Faculty of Human Ecology, Universiti Putra Malaysia, Selangor, Malaysia
Corresponding Author Email: gs61750@student.upm.edu.my

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Abstract
This paper presents an alternative possibility to the use of eco-friendly material on the vibrating membrane of a traditional Chinese musical instrument – *leiqin*. The study investigated on four soundboxes covered with python skin (representing the original material used for the vibrating membrane of the *leiqin*), and the remodeled eco-friendly imitation skin (the main component is polycarbonate membrane), each with the same diameter, placed under 4 different relative humidity conditions (30%RH, 50%RH, 70%RH, and 90%RH) inside a climate chamber. The sound intensity measured at every 8 hours for a total of 48 hours. In addition, both the python and imitation skins were soaked in water for 24 hours and weighed. Results indicated that the vibrating membrane using python skin exhibited high sensitivity to humidity, resulting in a wide change range of sound intensity and increased weight. Conversely, the imitation skin's vibratory membrane was unaffected by humidity. In summary, the eco-friendly imitation skin surpassed that of the python skin. Implications of this study are discussed.
Keywords: Eco-friendly, Vibrating Membrane, Humidity, Python Skin, Imitation Skin, Traditional Musical Instrument

Introduction

In China, the *leiqin* is a relatively young instrument, having been created only 100 years ago. It is renowned for its ability to convey a wide range of emotions through its rich tonal expression, and its distinct advantage of being able to produce a variety of sounds. It is common for performances such as folk songs, dances, and operas to be accompanied by the *leiqin* showcasing the unique musical culture and characteristics of the local area (Wang, 2011). The *leiqin* was created by a famous traditional folk musician of the Shandong province, Wang Dianyu in the late 1920s (Fu, 2011; Song, 1984). At present, it maintains a high stature in the musical landscape of Northern China. In 2008, it was included on a list of intangible cultural heritage by Tianjin City (Tianjin, 2008). In 2021, it was added to the fifth group of representative projects of intangible cultural heritage list at a provincial level by Shandong Provincial People's Government (Shandong, 2021).

The *leiqin* is made from brass and wood (Jia, 2015; Song, 1984), and it consists of a headstock, a slender neck, two tuning pegs, a shankou (a mobile unit that holds the strings in place), two strings, a soundbox, a vibrating membrane, a bridge, and a leg rest as shown in Figure 1 (Fu, 2011). Sound is produced by bowing on the strings.

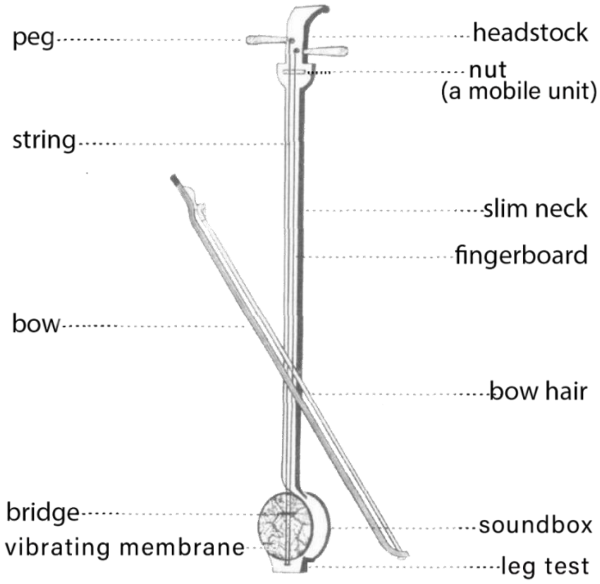


Figure 1. The structure of *leiqin*

The *leiqin* belongs to the membranophone family (Hornbostel & Sachs, 1961). The vibrating membrane is an essential component of the musical instrument (Siswanto et al., 2018), serving as both the resonator and radiator of sound energy. Its vibratory stability greatly influences the instrument's timbre, making it a crucial element. The traditional vibrating membrane uses the python skin, but there are issues concerning the longevity and sustainability of using python skin.

Firstly, python skin is known to be highly sensitive to humidity. The python skin as a whole is a protein fiber component with a network structure and exhibits favorable elastic characteristics (Baden et al., 1974; Ripamonti et al., 2009; Vakilian et al., 2019). However, the mechanical properties of python skin are influenced by its moisture content (MC). This relationship between humidity and MC is particularly relevant for *leiqin* players, as they have observed that the vibrating film of the *leiqin* undergoes changes in its properties with variations in the relative humidity (RH). The python skin has a tendency to expand when exposed to moisture. This expansion can lead to a reduction in sound quality. resulting in decreased sound quality (Lei & Tao, 2016). In a study conducted by Waltham & Kim (2018) on the physical properties of python skin, it was found that the optimal timbre and sound quality can only be achieved when the python skin is maintained at the appropriate humidity level.

Secondly, python skin is made mostly of protein fibers, which causes natural aging and is prone to damage caused by insects. In an interview with Wei (2004), the editor of the Musical Instrument Magazine (*乐器*), Song Fei who was a national first-class performer at the China Conservatory of Music, shared her insights "*after a period of use of musical instruments covered with wild python skin, the python skin will naturally age and the tension of the skin will become loose*". In China's hot summers or humid environments, the skin is prone to breed microorganisms, including bacteria, fungi, and mold, during the storage process, which may affect the structure and properties of the vibrating membrane (Wu, 2022). Duan Yuhe (2023), a Beijing fan of the *leiqin*, recounted his experience when asked about his impression of the python skin by Lu Saiya, a *leiqin* enthusiast, said that "he once went abroad for more than one month in the summer, and mentioned that the vibrating membrane of the *leiqin* he owned had been eaten by some small insects when he returned home because it had not been used for a long time" (Lu, 2023). In this example, the vibrating membrane had to be replaced, which resulted in a waste of resources.

Thirdly, raw materials for python skin musical instruments are in short supply. Typically, the Burmese python skin is used to create the vibrating membrane for the *leiqin* (Fu, 2011). In the wild, Burmese pythons typically reach a length of 5 meters, and the surface area of their skin is about 7 square meters (Barker et al., 2012.). According to research, it has been found that a five-meter-long python skin can be utilized to make up to six *leiqin* with good sound quality. This is due to the fact that not all parts of python skin are suitable for making musical instruments (Fu, 2017; Luan, 2014; Zeng, 2020). Li Jianmin (2022), a *leiqin* maker, said that the anal area of the python skin is very ideal because the vibrating membrane requires very high elasticity. However, the tail is small, just big enough to make one *leiqin*, which has a significant impact on the quantity of *leiqin* produced (Shu & Wan, 2022). Additionally, there are other membranophones that require python skins like the *erhu, the jinghu, the congas*, and others.

Finally, in 1988 China passed its Law on the Protection of Endangered Species after ratifying the UN Convention on the International Trade in Endangered Species (CITES) making it illegal to use and trade unlicensed pythons (Xu, 2005). In order to regulate the use of python skins, the State Forestry Administration of China had implemented a certification program for python skin sellers in Southeast Asia and musical instrument makers in China. As of January 1, 2005, new regulations require that musical instruments that made use of python skins would require a certificate from the State Forestry Administration, verifying that the python skin used in the production of these instruments were derived from farm-raised pythons, rather than wild ones. Moreover, when traveling or performing overseas, individuals are only allowed to take up a maximum of two python skin musical instruments out of China (*Regulations of the People's Republic of China on the Import and Export Management of Endangered Wild Fauna and Flora (2019 Revision)*, 2019; *Customs Law of the People's Republic of China,* 2015). This is problematic as certain musical performances or compositions may require a musician to play on more than two membranophones.

The reasons above have imposed certain constraints on the development of the *leiqin*. As a result, some researchers have begun experimenting with alternatives for python skin of *leiqin*. Among the handful, Fu Dingyuan in 1975, collaborated with Mr. Huang Jinlu, a musician from the Peking Opera Theater of China, to create a nylon vibrating membrane for the instrument (Fu, 2017). However, the resulting sound was muffled and lacked sufficient volume. Despite multiple attempts, the project was ultimately abandoned. In the pursuit of developing a vibrating membrane, Li Jianmin employed scanning film (ultrasound film used in hospitals). However, the process necessitated the film to be uniformly stretched and stressed at all three-hundred- and sixty-degrees during bonding, which proved to be a formidable challenge for human labor. The uneven force exerted resulted in rupture of the scanning film (Yang, 2019).
Above also provides an opportunity for this study to use eco-friednly materials to make the imitation skin of *leiqin.* After consulting, there isn't a comparison of scientific data on the humidity of *leiqin* python skin and *leiqin* imitation skin in the earlier studies. Therefore, this

study intends to utilize audio analysis method to conduct acoustic detection and a detailed analysis on the differences and similarities of the python skin and imitation skin produced for the *leiqin*. The aim is to observe the variations in sound intensity of the vibrating membrane under different relative humidity conditions and the water absorption capacity of both types of vibrating membrane. And the water absorption capacity of the two vibrating membrane was also tested using the immersion weighing method.

The study also aims to objectively compare and evaluate the two vibrating membranes, which not only can assist the public in choosing different types of *leiqin* options. In addition, it proposes a remodeled *leiqin* that is more eco-friendly, durable, sustainable, and that offers better performance, which can reduce the need to frequently replace the vibrating membrane, costs assiciated with maintaining the instrument are saved of performers, and benefit the preservation of rare pythons. This outcome is likely to encourage more young people and musicians to explore the *leiqin* and potentially inspire composers to create more works for this instrument. Finally, through the integration by combining musicology, materials science, and environmental sustainability, the outcome offer a comprehensive understanding of the possibility of using eco-friendly materials in the arts and culture.

Experimental Method

Music Instrument

1) Imitation Skin

The imitation skin vibrating membrane, specially developed for *leiqin* by Jinghu Studio of Beijing Zhenghui, China, was uniformly produced in September 2023. The materials used are eco-friendly an can be recycled and degraded. It produced in this study consists of five layers: the resin layer, reinforcement layer, waterproof layer, imitation cortex, and sunscreen layer, and has a thickness of 0.9 millimeter (mm), which is similar to the thickness of python skin (0.8mm) as shown in Figure 2.

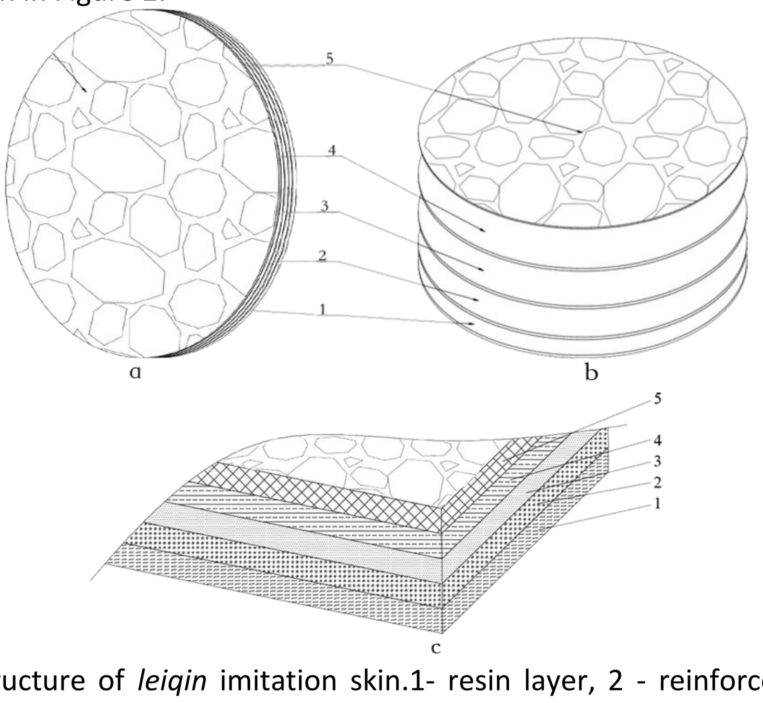


Figure 2. The structure of *leiqin* imitation skin.1- resin layer, 2 - reinforcement layer, 3 - waterproof layer, 4 - imitation cortex, 5 - sunscreen layer

a. overall structure. b. hierarchical structure. c. profile structure

The resin layer is made of poly(ethylene terephthalate) with ethylene powder to enhance scratch resistance. The reinforced layer is composed of Ultra-high-molecular-weight polyethylene (UHMWPE, UHMW), an exceptionally durable material known for having the highest impact strength among all thermoplastics currently produced (HL, 1988). It was utilized in imitation skin to enhance its resistance to wear and impact. The waterproof layer is made of polyethylene (PE, a polymer and the most commonly produced plastic Ammala et al (2011), with strong waterproof and moisture-proof ability. The imitation cortex is composed of polycarbonate membrane (PCM), which possesses exceptional toughness and high strength, making it resistant to tearing (Djurner et al., 1978). It is available in transparent, frosted, black, and colored variants. In the *leiqin* imitation skin, a combination of colored and black PCM is used to produce a grain pattern resembling that of python skin, to make it look and feel like real skin. The sunscreen layer of the imitation cortex is made of polyethylene glycol terephthalate (PET, the most common thermoplastic polymer resin of the polyester De Vos et al (2021), which provides excellent thermal insulation and blocks a majority of ultraviolet rays. This helps protect the imitation cortex from sun damage. The transparent sunscreen layer allows the patterns and lines of the imitation skin to be visible. Additionally, an antibacterial membrane is applied to one side of the imitation cortex (as shown in Figure 3). This membrane enhances the antibacterial effect, and the inclusion of sandalwood particles emits fragrance, improving the user experience. Moreover, the sandalwood particles have certain health care effects on the body.

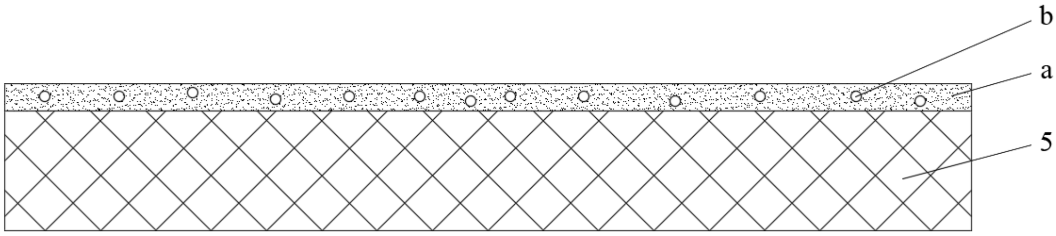


Figure 3. The sunscreen layer of imitation skin. a - antibacterial membrane, b - sandalwood particles

2) Python Skin

The python skin vibrating membrane used in this study is from Myanmar python provided by China Linyi Minglle Equipment Company, bearing the CNWM (China Wildlife Management and Utilization Management) special mark, as shown in Figure 4.

Figure 4. The CNWM and python skin

3) *Leiqin*

In order to maximize objectivity, the study utilized a total of eight *leiqin*, consisting of four *leiqin* with python skin vibrating membranes and four *leiqin* with imitation skin. All eight *leiqin* were manufactured by Bingguo Musical Instrument Factory in October 2022. The soundbox of each *leiqin* was made of 12 cm brass material, and the wood material used was from the same batch of Ivory Coast rosewood. Additionally, the strings, bows, bridges, and other accessories were all made from the same brand and batch of parts. Throughout the experiment, the vibrating membrane was the only variable. Figure 5. shows the python skin and imitation skin used in this experiment.

Figure 5. Two types of *leiqin*

Method

In this study, two methods were used to investigate the impact of humidity on the vibrating membrane of the *leiqin*. One method involved placing the soundbox, covered with python skin and imitation skin, in different relative humidity (RH) environments (30% RH, 50% RH, 70% RH, and 90% RH). The sound intensity of the vibrating membrane was measured every eight hours for 2 days, which made up for a total of 48 hours. The humidity control was achieved using the Memmert Climate Chamber HPP 400 (Germany), which provided a stable temperature and humidity environment, as shown in Figure 6. This ensured that each experiment was exposed to varying humidity levels for a specific duration, allowing for the examination of the effects of humidity on the sound intensity of the vibrating membrane.

Figure 6. Memmert Climate Chamber HPP 400

The second method involved submerging samples of python skin and imitation skin of the same size full in water for 24 hours under identical environmental conditions. After 24 hours, the weight change of each sample was measured using the BCS-XC-(LM) (A high-precision electronic balance), as shown in Figure 7.

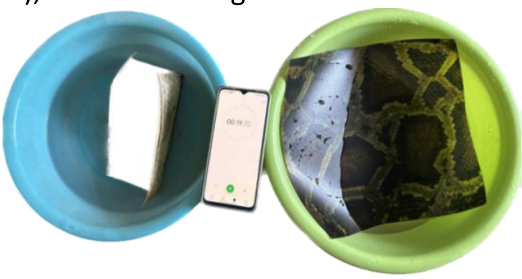


Figure 7. The same size samples were submerged in water

1) Data Collection

***Audio Recording*.** Two Neumann U87 Ai (omnidirectional microphones, Germany) were used to record sound samples in this experiment. One microphone was positioned 50° behind the left side of the player, pointing towards the back of the soundbox at a distance of 60 cm and at a height of 65 cm. The other microphone was placed 30° in front of the player, pointing towards the soundbox at a distance of 50 cm and a height of 70 cm, as shown in Figure 9. The recording system used for this study was a Pro Tools HD digital audio workstation with a sampling frequency of 48kHz and a sampling accuracy of 24bit. Audio analysis was conducted using Adobe Audition 14.2 software. The collected data was then organized and quantified using statistical tables, bar charts, and line charts to analyze and summarize the objective laws. During the test, Zhao Haohong, a student from the music Department of Jinan University, played the *leiqin* as shown in Figure 8. The player used both *f* and *p* techniques consecutively to play the a range of musical scales on the *leiqin* under different relative humidity conditions. In order to test the frequency of the vibrating membrane, we selected the two empty strings D4 and A4 (this way is the basis of tuning, and the most widely used in performance) of the inner and outer strings of the *leiqin* for analysis and comparison.

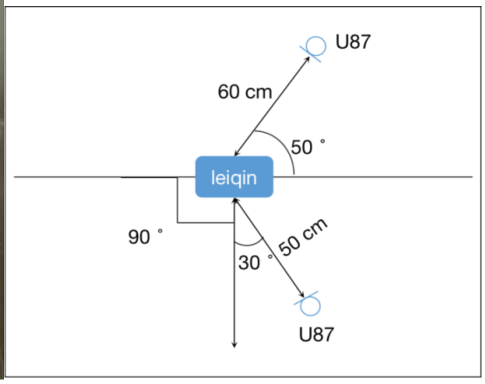


Figure 8. Actual recording *Figure 9.* The microphone and sound level meter mode of *leiqin*

2) Data Analysis

Audio Analysis**.** About the sound intensity analysis was conducted using GMAS (a universal music analysis system) and Adobe Audition 14.2 software. The magnitude of the influence of humidity on the acoustic vibration of the vibrating film is reflected by the tangent value (tan θ), and the formula is

$$\tan\theta = \frac{SI_2 - SI_1(dB)}{T_2 - T_1(h)} = \frac{\Delta SI(dB)}{\Delta T(h)}$$

Finally, all the collected data were sorted out and quantified by means of WPS-Excel statistical table and Visual Paradig line chart to analyze and summarize the existing objective laws.

Results and Discussion

Results

The impact of humidity on the vibrating membrane was assessed through various parameters including sound intensity and weight. Each of these parameters exhibited changes corresponding to humidity levels, allowing for deductions to be made regarding the influence of humidity on the vibrating membrane. Before the experiment started, the natural environment humidity was 53% (September 24, 2023, Beijing), and the sound intensity of python skin was recorded as 92.01dB (f) and 59.43dB (p), while the imitation skin registered 91.32dB (f) and 60.14dB (p). These test data can be more effectively compared to the experimental results, making conclusions more straightforward.

1) Influence of Relative Humidity On Vibrating Membrane of Python Skin

The mean values and trends of the maximum and minimum sound intensity of the vibrating membrane of python skin at various humidity levels are shown in Table 1. And Table 2 shows the specific number of the change trend.

Table 1
Sound intensity records of python skin and the change of sound intensity during the experiment by python skin

Time (hours)	Sound Intensity (dB)							
	30%RH		50%RH		70%RH		90%RH	
	f	p	f2	p2	f3	p3	f4	p4
8	81.22	54.24	92.34	60.23	91.37	60.58	88.13	57.37
16	85.32	56.91	92.04	59.57	90.54	58.93	85.31	50.26
24	86.11	57.36	90.75	59.11	89.43	57.45	75.58	47.44
32	86.78	58.93	89.79	58.34	88.21	55.28	70.13	40.58
40	86.98	60	88.53	57.54	86.89	53.98	64.23	36.24
48	87.3	60.51	88.11	56.89	85.42	52.76	62.62	33.79
Changes								

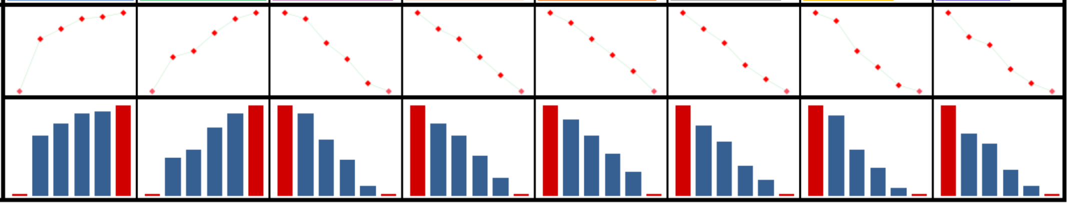
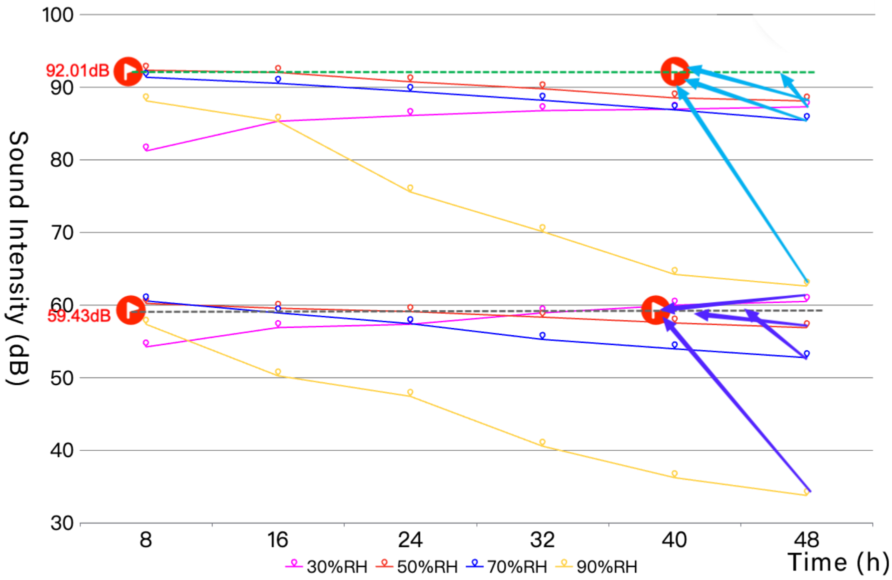


Table 2
The change of sound intensity during the experiment by python skin



The sound intensity values of the python skin vibrating membrane were measured at different relative humidity levels. These values provide insights into the correlation between humidity and the python skin. In the first measurement, at 30% RH, the sound intensity had the smallest value with *f* at 81.22 dB and *p* at 54.24 dB. After 48 hours, the parameter values reached their maximum, with *f* at 86.98 dB and *p* at 60.51 dB, indicating an upward trend. At 50% RH, the sound intensity had the biggest value with *f* at 92.34 dB and *p* at 60.23 dB. After 48 hours, the parameter values reached their minimum, with *f* at 88.11 dB and *p* at 56.89 dB, indicating an down trend. At 70% RH, the sound intensity had the biggest value with *f* at 91.37 dB and *p* at 60.58 dB. After 48 hours, the parameter values reached their minimum, with *f* at 85.42 dB and *p* at 52.76 dB, indicating an down trend. At 90% RH, the sound intensity had the biggest value with *f* at 88.13 dB and *p* at 57.37 dB. After 48 hours, the parameter values reached their minimum, with *f* at 62.62 dB and *p* at 33.79 dB, indicating an down trend. Among the different RH levels, it was observed that 30%RH demonstrates a consistent upward trend regardless of the factors *f* or *p*. The minimum value recorded is the initial test value, while the maximum value corresponds to the value obtained in the final test. However, even after 48 hours, the sound intensity of f remained lower than the test value in the natural environment, while the sound intensity of *p* was higher than the test value. On the other hand, 50%RH, 70%RH, and 90%RH exhibit a consistent downward trend, with the highest value observed in the first test and the lowest value observed in the last test. The changes in value follow a regular pattern and all show a similar direction of change.

Figure 10 presents the percentage change (PC) in sound intensity for four python skin samples after 48 hours in a humid environment. Its calculation formula is as follow:

$$Y = \frac{V2 - V1}{V1} \times 100\%$$

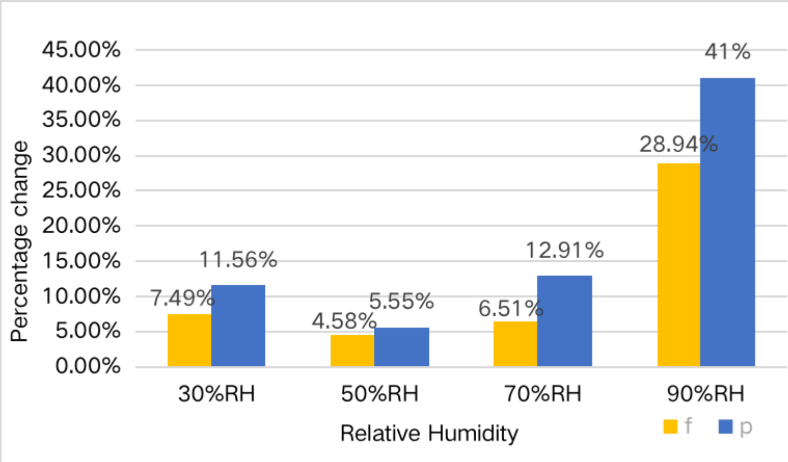


Figure 10. Percentage change in sound intensity

As can be seen from the figure, at 30% RH, PC of *f* is 7.49%, *p* is 11.56%; at 50% RH, PC of *f* is 4.58%, *p* is 5.55%; at 70% RH, PC of *f* is 6.51%, *p* is 12.91%; at 90% RH, PC of *f* is 28.94%, *p* is 41%. These data clearly demonstrates that the percentage change of *p* is consistently higher than that of *f*, regardless of the specific humidity level. Additionally, the results indicate that when the relative humidity is 50%, the vibrating membrane of python skin exhibits the least change in mean sound intensity, *f* is 4.58%, *p* is 5.55%; when the relative humidity is 90%, the vibrating membrane of python skin exhibits the most change in mean sound intensity, *f* is 28.94%, *p* is 41%.

2) Influence of Relative Humidity on Vibrating Membrane of Imitation Skin

The statistics of the average values and variation trend of maximum and minimum sound intensity of imitation skin under the influence of different relative humidity as shown in Table 3. All the values change irregularly. The study found that the sound intensity of the imitation skin vibrating membrane does not change much, whether it is *f* or *p*, when the intensity is *p*, the sound intensity is higher than that in the natural environment. It can be seen that the relative humidity had minimal impact on the sound intensity of the imitation skin vibrating membrane. The slight changes recorded in the table could be attributed to the varying force exerted by the player while playing the *leiqin*. And Table 4 shows the specific number of the change trend.

Table 3
Sound intensity records of python skin and the change of sound intensity during the experiment by imitation skin

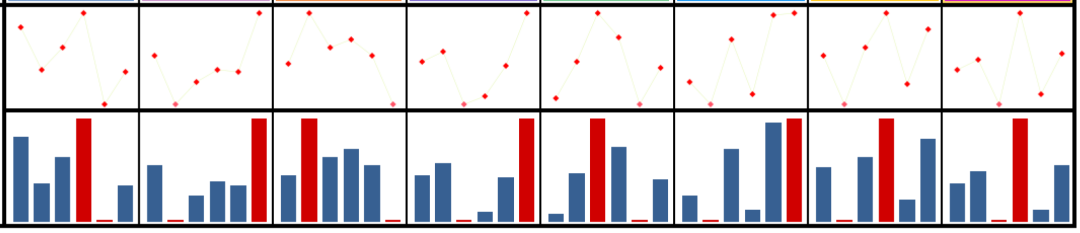
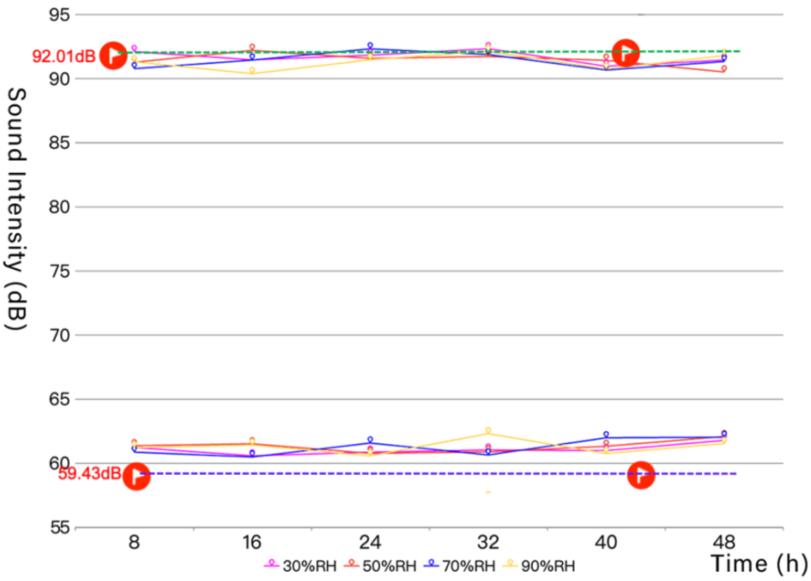
Time (hours)	Sound Intensity (dB)							
	30%RH		50%RH		70%RH		90%RH	
	f	p	f2	p2	f3	p3	f4	p4
8	92.11	61.23	91.28	61.37	90.78	60.87	91.32	61.22
16	91.47	60.58	92.21	61.52	91.45	60.49	90.39	61.43
24	91.83	60.87	91.58	60.77	92.33	61.58	91.48	60.58
32	92.34	61.04	91.73	60.89	91.88	60.65	92.14	62.31
40	90.97	60.99	91.43	61.33	90.67	61.99	90.75	60.76
48	91.45	61.79	90.52	62.09	91.34	62.03	91.81	61.54
Changes								

Table 4
The change of sound intensity during the experiment by imitation skin



3) Weight of the Vibrating Membrane in Water

The weight of the python skin and imitation skin before and after being soaked in water as shown in Table 5. The initial weight of python skin was 33.4g, which increased to 58.9g after soaking, resulting in a weight gain of 25.5g. Similarly, the imitation skin had an initial weight of 26.4g, which increased to 27.5g after soaking, indicating a weight gain of 1.1g.

Table 5
Weight of the vibrating membrane before and after soaking in water

Vibrating Membrane	Weight (g)			
	Before	After	Deviation	Changes
Python Skin	33.4	58.9	25.5	
Imitation Skin	26.4	27.5	1.1	

Discussion

This experiment investigated the impact of varying relative humidity on the sound intensity of python skin and imitation skin, as well as the weight changes of the two vibrating membranes after complete immersion in water. The experimental data results provide insights into the influence of humidity on the sound produced by vibrating membranes.

The moisture absorption performance of python skin, being a biological material capable of absorbing water, is not constant. Regardless of the RH environment, as the MC of python skin reaches its peak, the value of tan θ decreases, leading to a gradual decrease in moisture absorption performance and a tendency for sound intensity to balance. Therefore, when the humidity in the environment is higher, the python skin absorbs water, causing the cortex to become soft. Conversely, the cortex hardens by releasing its own stored water. As demonstrated in the experiment, the weight of the python skin vibration film increased by 25.5 gram (g) after being immersed in water for 24 hours. However, upon further immersion in water, the weight no longer increased. This can be attributed to the fact that the MC of the python skin had reached its peak and the humidity level in the water remained constant. The intensity of the sound is displayed when the python skin is in 30% RH, the sound intensity exhibited an upward trend over time, gradually approaching the value observed in the natural environment test. The sound intensity change observed at 50% RH is the most consistent, indicating an advantage in all humidity levels. It can be seen that the moisture absorption of python skin varies with different RH levels and over time, resulting in different sound effects. Additionally, this value closely aligns with the sound intensity measured in natural environments. It is further hypothesized that the python skin is most stable at around 50% RH, resulting in optimal sound quality for musical instruments. Excessive humidity, either too high or too low, can disrupt the moisture balance of the python skin, thereby affecting the performance of the musical instrument.

The main material used for the imitation skin is polycarbonate membrane (PCM), a type of chemical material. During the experiment, the *leiqin*, which acts as the imitation skin vibration membrane, was immersed in water. It was observed that the weight of the *leiqin* did not significantly increase. Additionally, the sound intensity remained unchanged even with variations in humidity. These findings provide sufficient evidence to support the conclusion that the imitation skin exhibits excellent waterproof performance. If used as the vibrating membrane of the *leiqin*, its acoustic performance will remain unaffected by the surrounding environment. Additionally, it will help reduce resource wastage caused by frequent replacement of the vibrating membrane.

Conclusion

The results indicate that high humidity causes the vibrating membrane of python skin to expand as a result of water absorption. This expansion reduces tension and subsequently decreases the sound produced.

Based on objective data, this study has concluded that humidity significantly impacts the acoustic performance of the vibrating membrane of python skin, whereas the imitation skin remains largely unaffected by humidity and maintains its sound quality regardless of conditions. The acoustic indexes of the imitation skin's vibrating membrane exhibit certain advantages over python skin, and the sound characteristics of the imitation skin closely resemble those of python skin, and the use of eco-friendly materials, can be mass-produced, there will be no shortage of supply for *leiqin*. Therefore, the imitation skin can serve as a suitable sample for further development and refinement of the *leiqin*.

The performance of the *leiqin* of imitation skin cannot be solely determined by objective measurement data. Since music is an auditory art and musical instrument performance is also a form of art, acoustic indicators alone cannot be the sole basis for evaluating the advantages of imitation skin and python skin. The quality of the *leiqin* sound as an art form must be evaluated subjectively through people's hearing. Additionally, the subjective experience of the player is essential in judging the performance of the *leiqin* from a behavioral perspective. Therefore, subjective evaluation plays a crucial role in obtaining the final evaluation results. However, this paper focuses on objective measurement and comparison, with the hope of providing a reference for future subjective evaluations based on this foundation.

From the limited research scope of this study, it was found that the *leiqin* of imitation skin demonstrated a higher overall advantage compared to the python skin in terms of water absorption performance and sound intensity. However, it is uncertain if this advantage can be subjectively evaluated. In other words, besides considering environmental humidity, there is no definitive conclusion on whether to use python skin or imitation skin. Nevertheless, considering economic factors, environmental impact, and the need for sound stability, these aforementioned advantages are certainly worth considering.

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