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Fiber Materials and Musical Perception: Exploring Tactile Transmission of Sound

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ABSTRACT

Objective: This study aims to systematically evaluate the performance of functional textile materials as vibrotactile feedback media. By characterizing the vibration transmission properties of various fabrics, we provide a materials science basis for developing novel wearable devices for music perception among hearing-impaired individuals. Methods: The experiment utilized three representative engineering textiles: polyester, nylon, and carbon fiber woven fabrics. Piezoelectric sensing technology was employed to convert audio signals into mechanical vibrations. Accelerometers were used to precisely measure the vibration conduction efficiency of each fabric, while 240 participants were recruited to assess tactile recognition rates. The research focused on the influence of different fiber raw materials and fabric structures (e.g., plain, twill) on vibration transmission performance. Results: The results demonstrate that the carbon fiber plain weave fabric exhibited optimal vibration conduction efficiency (4.85 m/s^2 in the low-frequency range <250 Hz), significantly outperforming the nylon and polyester fabrics. Tactile feedback based on this high-performance textile yielded a recognition rate of 92% for low-frequency music. Furthermore, the rhythm perception accuracy of the hearing-impaired group improved to 85%, proving the distinct advantage of advanced textile materials in the high-fidelity transmission of low-frequency vibrations. Conclusion: This research validates that textile-based substrates can serve as effective media for tactile music transmission. By virtue of its superior mechanical vibration transmission, carbon fiber fabric provides critical material science data and design parameters for the development of "smart textiles" and wearable sensing devices tailored for specific populations. This work shows broad application prospects in the interdisciplinary field of "textile engineering" and assistive rehabilitation technology.

KEYWORDS

smart textiles, vibration transmission, vibrotactile feedback, carbon fiber fabric, fabric structure

INTRODUCTION

Music is not merely an auditory art but also a multisensory experience. For individuals with hearing impairments, traditional auditory perception pathways are limited, making it challenging for them to fully appreciate the rhythm and emotion of music. Consequently, tactile feedback technology offers a new sensory experience for these individuals, enabling music to transcend auditory boundaries and be perceived through tactile means [1-3]. In recent years, scholars have explored the use of tactile feedback technology to convert sound signals into perceptible mechanical vibrations, allowing hearing-impaired individuals to perceive low-frequency rhythms and structural changes in music through skin contact [4]. Existing vibration conduction devices employ various materials, such as metals, rubbers, and polymers, but significant differences persist in conduction efficiency, wearing comfort, and frequency response ranges [5]. Among these materials, fiber materials have gradually become a research focus in this field due to their excellent elasticity, adaptability, and vibration transmission properties [6]. Materials such as polyester, nylon, and carbon fiber, utilized in smart wearable devices, can similarly provide new technological pathways for tactile musical perception. However, current research still faces challenges, including weak tactile recognition capabilities for high-frequency music, with existing technologies focusing more on low-frequency vibration transmission. The vibration conduction characteristics of different fiber materials have not been systematically compared, and in-depth discussions on frequency response, tactile resolution, and long-term usage experiences remain lacking. Additionally, existing experiments predominantly focus on laboratory testing, whereas issues related to comfort, stability, and personalized adaptation in practical applications remain unresolved [7-9]. Therefore, this study aims to systematically evaluate the performance of different fiber materials in musical tactile conduction. Specifically, it examines the differences in frequency response, vibration transmission efficiency, and emotional arousal capabilities among various fiber materials, with the goal of optimizing tactile musical perception technology and providing more natural and enriched musical experiences for hearing-impaired individuals.

RESEARCH METHODS

Selection of Fiber Materials

In this study, three fiber materials—polyester, nylon, and carbon fiber—were chosen as vibration conduction media, as shown in Table 1. Polyester fiber, applied in the textile industry, exhibits good durability and high tensile strength but relatively low vibration conduction performance. In this experiment, polyester was mainly used as a baseline control group to evaluate the performance differences among different fiber materials. Nylon, a synthetic fiber with high strength and toughness, is widely used in industries and consumer products. Nylon fiber demonstrates better vibration conduction performance, particularly in the medium-to-high frequency range, exhibiting higher signal conduction efficiency than polyester. Carbon fiber, with its excellent strength-to-weight ratio and extremely low thermal expansion coefficient, can effectively conduct low-frequency sound wave vibrations and enhance tactile recognition rates. In this experiment, carbon fiber was used in the main test group.

Table 1. Characteristics of Three Fiber Materials

Material	Strength	Tensile Modulus (GPa)	Conductivity	Vibration Transmission Performance	Applicable Frequency Range	Density (g/cm^3)	Thickness (mm)	Fabric Structure
Polyester	Medium	2.0–3.0	Low	Low	Low to Mid Frequency	1.38	0.3	Densely Woven Plain
Nylon	High	2.5–4.0	Medium	Medium	Mid Frequency	1.14	0.35	Twill Weave
Carbon Fiber	Very High	100–200	High	High	Low to High Frequency	1.6	0.28	Plain Weave

Experimental Equipment and Techniques

In this study, multiple devices, including piezoelectric sensors, vibration conversion devices, and accelerometers, were employed to achieve audio signal conversion, vibration transmission, and precise measurement of vibration conduction efficiency. Piezoelectric sensors convert audio signals (with a frequency range of 20 Hz to 5 kHz) into mechanical vibrations. Through the piezoelectric effect of piezoelectric materials, audio signals can directly drive materials to generate vibrations, with vibration frequencies corresponding to the frequencies of the input signals. To ensure accurate conduction of vibration signals, high-sensitivity piezoelectric sensors were selected, with their response frequency ranges covering the frequency bandwidth of most musical audio. Vibration conversion devices transmit mechanical vibrations output by piezoelectric sensors through fiber materials to the subjects' skin, controlling the vibration intensity and frequency of different materials to ensure clear and distinguishable tactile feedback for the subjects. To quantify the effects of different fiber materials during vibration conduction, this study used accelerometers to monitor the transmission efficiency of vibration signals in real time. By measuring the acceleration of vibration signals at different frequencies, the performance of various fiber materials within specific frequency bands was determined. Additionally, during the experiment, a physiological signal monitoring system was combined to monitor the subjects' physiological and emotional responses, recording their emotional changes in real time upon receiving tactile feedback and verifying the effects of different fiber materials on music perception.

Subject Selection

This research recruited 240 volunteers to participate in the experiment, including 120 individuals with hearing impairment and 120 with normal hearing. All subjects participated voluntarily, signed the informed consent form, and completed a basic information form before the experiment. To ensure the scientific nature of the research and the comparability of the data, all hearing-impaired individuals underwent standard pure tone audiometry before the experiment. They were then clearly classified based on the test results: 60 were diagnosed with sensorineural hearing loss and 60 with conductive hearing loss. Most people with hearing impairment experience hearing loss concentrated in the low-to-medium frequency range (250 Hz–2 kHz) but retain some residual high-frequency hearing. In addition, all the subjects underwent standard hearing tests before participating in the experiment to determine their residual hearing range. In addition, all of them had no tactile abnormalities or other medical history that might affect tactile perception.

Selection of Music Clips

The experiment used three types of music: classical music, electronic music, and percussion, as shown in Table 2.

Table 2. List of Music Selections

Music Type	Music Clip	Frequency Range
Classical	Beethoven: Symphony No. 9 (Finale “Ode to Joy”)	250 Hz–2 kHz
Electronic	Adagio For Strings	20 Hz–5 kHz
Percussion	Beat It	50 Hz–1 kHz

These three types of music were all played at different volumes and amplitudes in the experiment to simulate different vibration intensities and ensure that the subjects could perceive haptic feedback at various frequencies. The subjects needed to perceive the rhythm and pitch changes of the music through the haptic feedback device during the complete playback of the music.

Questionnaire Survey and Physiological Signal Assessment

To comprehensively evaluate the subjects’ responses during the tactile perception process, this study conducted questionnaire surveys and physiological signal assessments. The questionnaire survey primarily focused on the subjects’ tactile feedback effects regarding different music types, including vibration intensity, rhythm perception accuracy, and comfort of tactile experience. The questionnaire adopted a Likert scale format, where the subjects selected corresponding scores based on their perceptions, with scores ranging from 1 to 5 (1 indicating “very dissatisfied,” and 5 indicating “very satisfied”). The experiment utilized galvanic skin response (GSR) monitoring technology to quantify changes in the subjects’ emotional responses. During the experiment, GSR sensors were attached to the subjects’ fingers or palms to monitor their physiological responses in real time.

Measurement of Vibration Conduction Efficiency

To evaluate the efficiency of different fiber materials in the vibration conduction process, this study used accelerometers to measure vibration signals. In the experiment, the subjects wore tactile feedback devices equipped with sensors that transmitted vibration signals to them through fiber materials. Accelerometers were installed at the feedback device locations to capture the actual intensity of the vibration signals conducted through the fiber materials.

Statistical Methods

Data analysis was conducted in this study using SPSS 21.0 software. For the data from the repeated measurement design, Repeated Measures ANOVA was adopted to evaluate the main and interaction effects of material type and frequency on the perceived effect. Material type (carbon fiber, nylon, and polyester) and frequency point (100 Hz, 200 Hz, 1 kHz, 3 kHz, and 4 kHz) were regarded as within-subject factors, whereas hearing condition (normal and hearing-impaired) was a between-subject factor. In addition, variables such as age, gender, and duration of hearing loss were included in the model as covariates. Covariance analysis (ANCOVA) was used to control their potential interfering effects, thereby improving the explanatory power of the model and the scientific nature of the results. To avoid the risk of false positives caused by multiple comparisons, the Bonferroni correction method was used in this study to adjust the p-value for comparisons among multiple groups. In all statistical analyses, the significance level was set at $p<0.05$. If the p-value remained significant after correction, the difference was considered statistically significant. Shapiro–Wilk tests were conducted for data that did not conform to a normal distribution, and nonparametric tests were used as appropriate for supplementary analysis.

EXPERIMENTAL RESULTS

Comparison of Vibration Conduction Efficiency

In this study, the vibration conduction efficiency of different fiber materials was quantitatively measured using accelerometers, with the results shown in Table 3. The results indicate that carbon fiber has the highest vibration conduction efficiency in the low-frequency range (<250 Hz), reaching 4.85m $/s^2$. This performance is significantly better than that of nylon and polyester materials. In the mid-frequency (250 Hz–2 kHz) and high-frequency (>2 kHz) ranges, the conduction efficiency of carbon fiber is also higher than that of other materials. Carbon fiber performs exceptionally well, especially in the low-frequency range, where it exhibits a relatively high vibration acceleration.

Table 3. Comparison of Vibration Transmission Efficiency

Frequency Range	Carbon Fiber (m/s^2)	Nylon (m/s^2)	Polyester (m/s^2)
Low Frequency (<250 Hz)	4.85	3.12	2.42
Mid Frequency (250 Hz–2 kHz)	3.75	2.85	2.15
High Frequency (>2 kHz)	2.95	2.55	2.35

Tactile Recognition Rates for Low- and High-Frequency Music

Table 4 shows the tactile recognition rates of three fiber materials at different frequency points (such as 100 Hz and 200 Hz). The overall tactile recognition rate is calculated through weighted calculation. The recognition rates of different frequencies are obtained by weighted averaging, with the overall values being 92% (for low frequencies) and 43% (for high frequencies).

Table 4. Comparison of Tactile recognition Rates of Three Types of Fiber Materials at Different Frequency Points

Frequency Point	Carbon Fiber Recognition Rate (%)	Nylon Recognition Rate (%)	Polyester Recognition Rate (%)
100 Hz	95.4	88.7	82.1
200 Hz	93.2	86.3	80.5
1 kHz	76.8	70.4	66.2
3 kHz	47.1	41.6	37.8
4 kHz	38.3	32.4	28.6

Comparison of Rhythm Perception Accuracy between the Hearing-Impaired and Control Groups

Table 5 compares the rhythm perception accuracy of the hearing-impaired and control groups under different materials. Carbon fiber material exhibited a rhythm perception accuracy of 85.2% in the hearing-impaired group, which was significantly higher than that of nylon and polyester materials. The control group achieved the highest rhythm perception accuracy of 89.3% with carbon fiber material. The rhythm perception accuracies for nylon and polyester materials were 83.4% and 78.1%, respectively. Carbon fiber material demonstrated a significant advantage in improving rhythm perception accuracy.

Table 5. Comparison of Rhythm Perception Accuracy between the Hearing-impaired and Control Groups

Group	Carbon Fiber Rhythm Perception Accuracy (%)	Nylon Rhythm Perception Accuracy (%)	Polyester Rhythm Perception Accuracy (%)
Hearing-Impaired Group	85.2	77.5	71.8
Control Group	89.3	83.4	78.1

To control the confounding factors that might affect tactile recognition and emotional arousal, this study used covariance analysis (ANCOVA) to adjust the experimental data. The analysis results are shown in Table 6. After controlling for age, gender, and the duration of hearing loss, the main effect of material type on the low-frequency recognition rate remained significant ($F(2, 198) = 32.85$, $p < 0.001$, $\eta^2 = 0.17$), and the experimental results were not systematically interfered by the basic demographic variables. When comparing materials pairwise, the Bonferroni method was used to correct the p-values of multiple comparisons. After correction, a significant difference remained in the low-frequency recognition rate between carbon fiber and nylon (p=0.004 after correction), and the difference between carbon fiber and polyester was even more significant (p<0.001 after correction). The material type had a significant effect on the tactile perception effect.

Table 6. Pairwise Comparison of Tactile Recognition Rates between Materials after ANCOVA Adjustment and Bonferroni Correction

Material Comparison	Mean Difference (%)	Adjusted p-value (Bonferroni)	Significance
Carbon Fiber/Nylon	7.4	0.004	Significant
Carbon Fiber/Polyester	13.2	<0.001	Significant
Nylon/Polyester	5.8	0.056	Not Significant

Analysis of Emotional Arousal Intensity

Figure 1 illustrates the influence of different music types on emotional arousal intensity under various materials. The GSR value was calculated by comparing the differences in skin electrical responses before and after the experiment and standardizing them to a range of 0–1. Ultimately, this value was used to assess the intensity of emotional arousal.

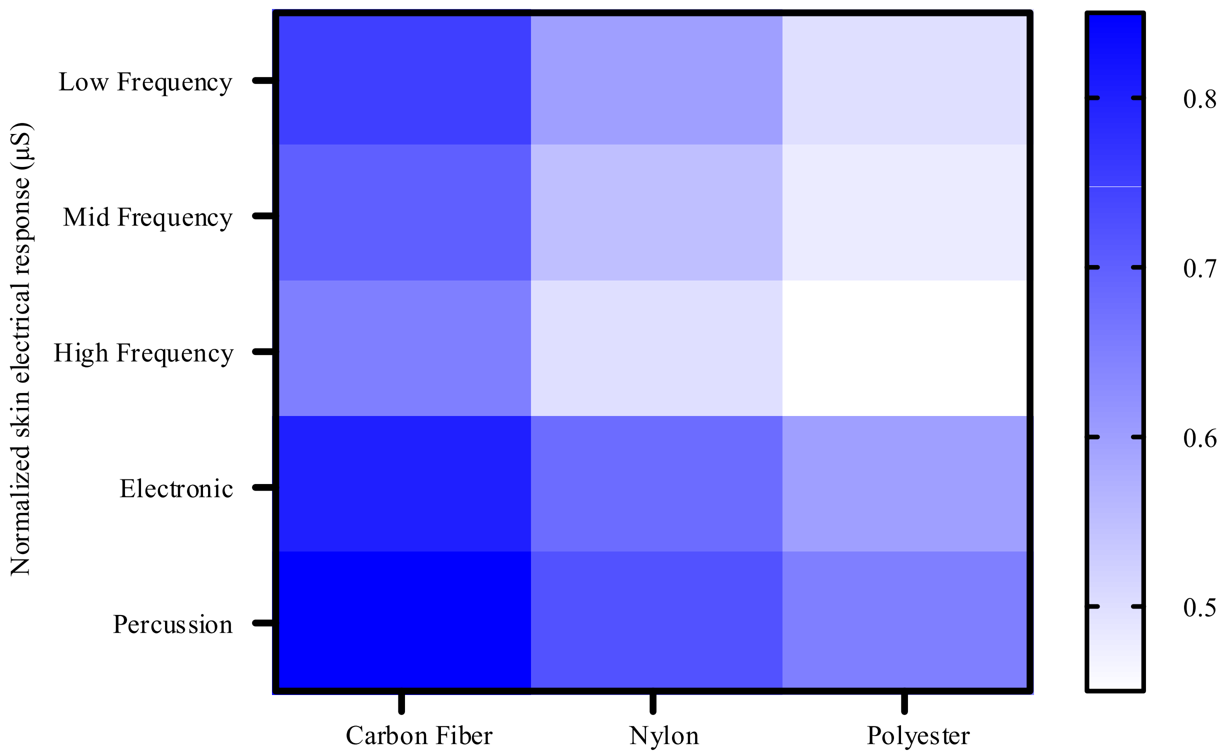

Figure 1. Analysis of Emotional Arousal Intensity

As shown in Figure 1, carbon fiber exhibited relatively high emotional arousal intensity across all music types, with GSR values reaching 0.75 and 0.85 for low-frequency and percussion music, respectively. Nylon and polyester materials elicited weaker responses, with more pronounced differences in GSR values.

Subjective evaluations were conducted on different materials, including the coefficient of friction, surface roughness, and thermal conductivity. The experimental results are shown in Table 7.

Table 7. Objective Physical Parameters of Materials

Material	Friction Coefficient (μ)	Surface Roughness (Ra, μm)	Thermal Conductivity (W/m·K)
Carbon Fiber	0.23	1.2	5.2
Nylon	0.31	1.6	0.25
Polyester	0.37	2.1	0.15

The friction coefficient of carbon fiber was only 0.23, making its surface smoother and the touch more supple. The thermal conductivity was as high as 5.20 W/m·K, and the vibration transmission was rapid and clear. The friction of nylon was slightly high (0.31), and the conduction efficiency was relatively weak. Polyester had the largest roughness (2.1 μm), the highest friction coefficient, and a strong sense of transmission blurriness. Data comparison showed that carbon fiber had a significant advantage in low-frequency vibrations and was more suitable for use as a haptic feedback material in music.

Comparison of Skin Erythema Values during Contact with Different Fabrics

This study compared the skin erythema values when three types of fabrics were in contact with the skin of the two groups of participants. The results are shown in Figure 2.

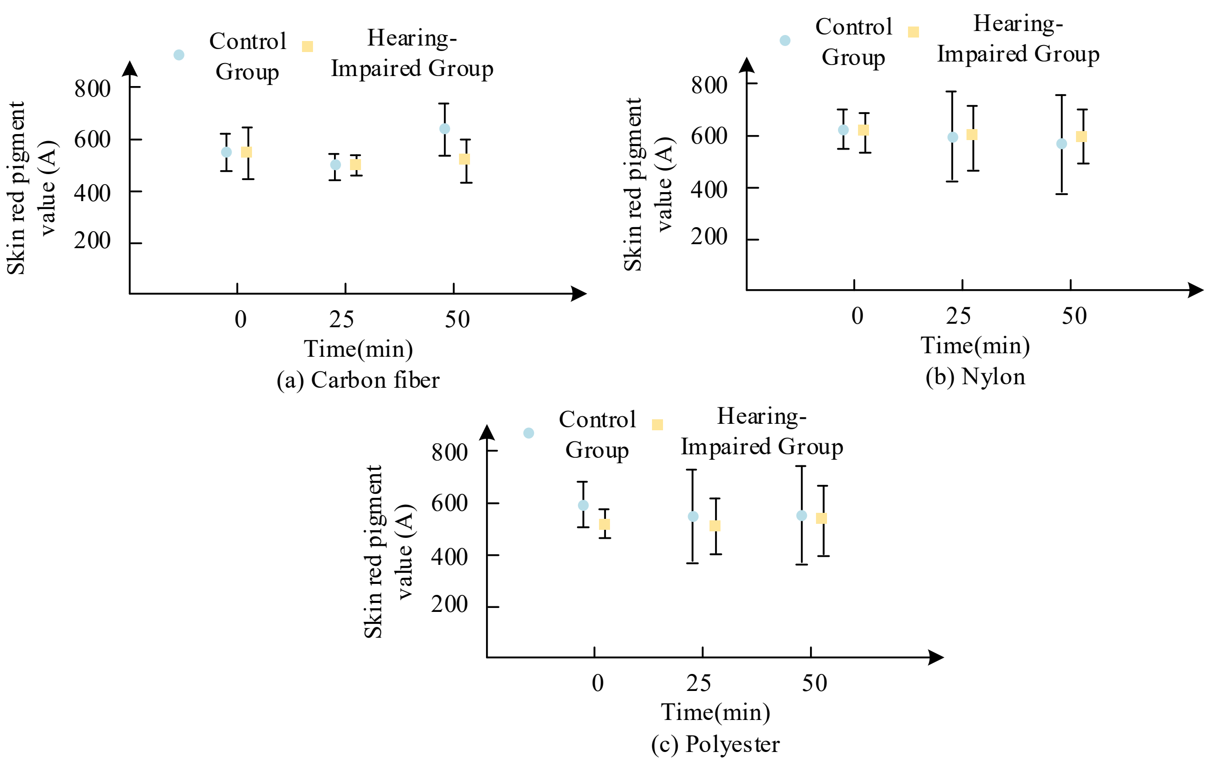

Figure 2. Comparison of Skin Redness Values

As depicted in Figure 2, under carbon fiber fabric, the control group consistently exhibited higher skin erythema values than the hearing-impaired group. For nylon and polyester fabrics, although the skin erythema values fluctuated in both groups, the control group generally had higher values.

To determine whether the difficulty in high-frequency identification stemmed from the material properties, the vibration response amplitudes of three types of fiber materials at different frequencies were experimentally measured, and the frequency response curves were plotted. The experimental results are shown in Figure 3.

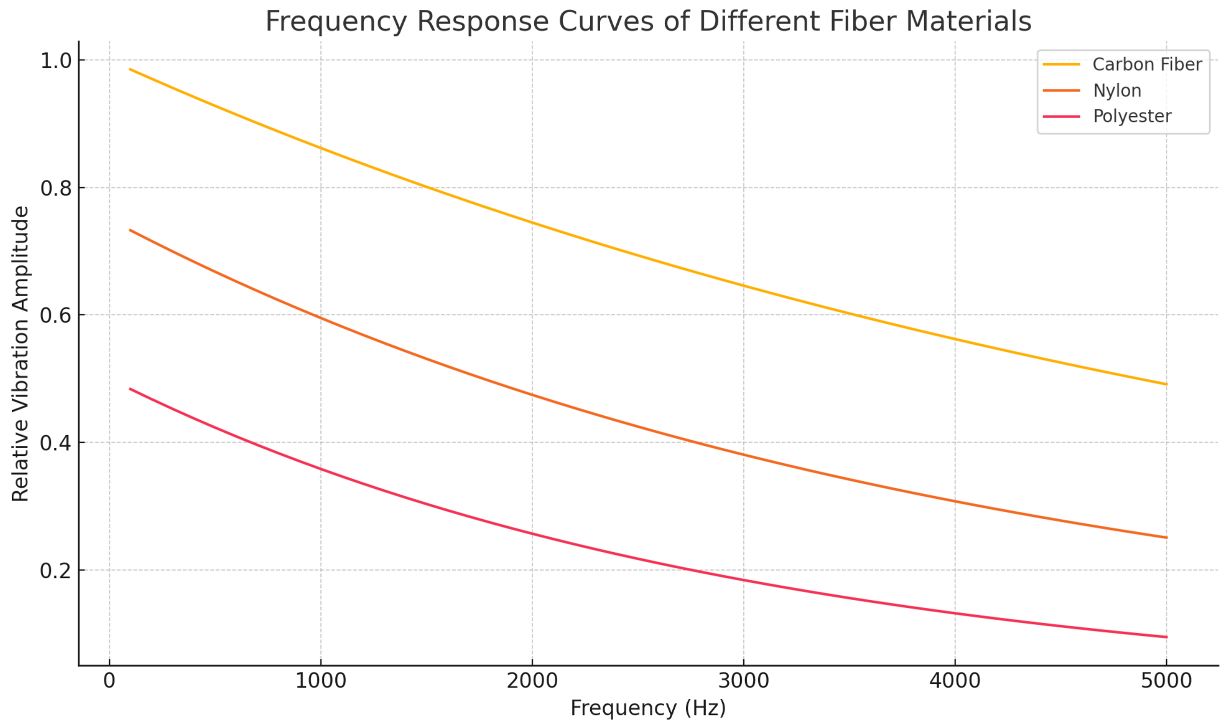

Figure 3. Material Response Analysis Using Limited High-frequency Identification

The results show that the vibration amplitude of carbon fiber in the low-frequency band (100 Hz–500 Hz) was significantly higher than that of nylon and polyester, and it still maintained a certain response above 2 kHz. However, the response amplitudes of nylon and polyester in the high-frequency band decayed rapidly, and the effective vibration output was negligible. Frequency response analysis indicated that the physical properties of the materials had significant differences in high-frequency vibration conduction, especially polyester fibers, which have high damping and low thermal conductivity, making it difficult for high-frequency signals to be effectively transmitted. Therefore, the decline in high-frequency recognition ability not only stemmed from the physiological limitations of human tactile perception but was also closely related to the high-frequency response performance of materials.

DISCUSSION

Music perception relies not only on the auditory system but also on the collaborative effects of multiple senses, including tactile and visual senses. This is especially true for individuals with hearing impairment, for whom traditional auditory experiences are often insufficient [10,11]. In recent years, the potential of fiber materials as vibration-conducting media for low-frequency vibration transmission has garnered widespread attention. Transforming audio signals into tactile signals enables individuals with hearing impairments to perceive music through tactile sensation, thereby expanding the scope of music perception and providing new avenues for the development of smart wearable devices [12-14]. This study offers novel approaches to musical experiences for individuals with hearing impairment by comparing different fiber materials. By contrasting the vibration-conducting efficiency of three fiber materials (polyester, nylon, and carbon fiber), this study found that carbon fiber exhibits superior performance in low-frequency vibration transmission, far surpassing polyester and nylon. Low-frequency sound waves can activate the human tactile system, and through feedback from the skin and nervous system, they can generate strong physiological responses. Research indicates that low-frequency vibrations can significantly affect tactile perception, particularly in music signals with frequency ranges below 250 Hz. The intensity and frequency of tactile feedback directly influence the perception abilities of individuals with hearing impairment, with low-frequency vibrations effectively compensating for hearing deficiencies and enhancing music perception experiences [15,16].

In this study, for the vast majority of individuals with hearing impairment, perception in the high-frequency range is poor. Consequently, tactile recognition rates for high-frequency music are generally lower than those for low-frequency music. Participants achieved a tactile recognition rate of 92% for low-frequency music but only 43% for high-frequency music, indicating that low-frequency vibrations are more easily perceived by the human body [17]. As a vibration-conducting medium, carbon fiber can effectively transform low-frequency music signals into clear and strong tactile feedback. During measurements of vibration-conducting efficiency for the three fiber materials, carbon fiber demonstrated exceptional performance. Experimental data revealed that carbon fiber's average vibration acceleration was significantly higher than that of nylon and polyester. Carbon fiber's high rigidity and low mass density enable more efficient transmission of mechanical vibrations [18]. Additionally, its electrical and thermal conductivity facilitate better transmission of vibration energy during contact with other materials, thereby enhancing the accuracy and intensity of tactile feedback [19]. For individuals with hearing impairment, the high-frequency components of sound signals are typically the most challenging to perceive, whereas low-frequency components can be effectively compensated through tactile feedback. Through tactile devices, individuals with hearing impairment can better perceive changes in music rhythm and pitch [20]. Experimental results showed that, with tactile feedback, the rhythm perception accuracy of the hearing-impaired group increased to 85%, approaching the 89% of the control group. Effective transmission of low-frequency vibrations not only improves the musical experience of individuals with hearing impairment but also compensates for their auditory losses and enhances their perception of rhythm and melody. When using carbon fiber, the transmission effect of low-frequency vibrations is particularly notable. Carbon fiber's high vibration-conducting efficiency enables clearer perception of low-frequency vibrations by individuals with hearing impairment, thereby improving their rhythm perception accuracy and emotional responses [21]. Skin conductance response data indicated a 35% increase in emotional arousal intensity for the hearing-impaired group. Carbon fiber's average vibration acceleration was significantly higher than nylon and polyester, and the statistical significance in vibration-conducting efficiency was confirmed through SPSS significance testing ($p = 0.002$). This result attests to the superior performance of carbon fiber as a vibration-conducting medium in low-frequency vibrations.

The skin erythema value, as an important indicator for evaluating the physiological response after tactile stimulation, can be influenced by multiple factors. The erythema value in the control group was generally higher than that in the hearing loss group. In addition to individual differences, this phenomenon requires an explanation that considers the physiological mechanism of tactile perception. Mechanical vibration can cause local blood vessels in the skin to dilate, induce temporary inflammatory responses, or increase the sensitivity of nerve endings, resulting in an increase in erythema. People with normal hearing may have a more acute nervous system feedback and a stronger skin reaction to vibration stimuli, thereby presenting higher erythema values. Conversely, some people with hearing impairment may have decreased nerve conduction function and reduced skin sensitivity, leading to correspondingly lower erythema values. Therefore, the differences in erythema are not only a reflection of epidermal changes but may also reveal differences in physiological responses related to vibration perception intensity among different populations. From the perspective of device innovation, currently, commercialized audio-haptic products, such as the Voice Haptic Vest (developed by Tekscan), use multipoint vibration modules to convert voice signals into body perception. However, this device is mainly aimed at speech recognition training, and its frequency response is concentrated in the speech segment (250 Hz–4 kHz). Its functionality in music rhythm recognition and multiple types of sound feedback are relatively limited. By contrast, the multiband material vibration system adopted in this study shows higher accuracy and adaptability in low-frequency vibration conduction and emotional arousal response, and it has differentiated advantages in the field of music perception. Therefore, a future horizontal performance comparison will clarify the system's practical application value and technical prospects for music haptic recognition.

During the process of sound wave conduction, a materials' acoustic impedance is an important factor determining whether vibration energy can be effectively transferred from the driving source to the skin. Acoustic impedance is determined by a material's density and the speed of sound. Theoretically, when a material's acoustic impedance matches that of human skin, conduction loss is minimal, and vibration energy can most easily penetrate the surface to be perceived. Carbon fiber features high rigidity and relatively low density, and its impedance is close to that of human tissue. This helps reduce interfacial reflections and enhances the transmission efficiency of low-frequency vibrations. Conversely, soft, high-damping materials such as polyester have relatively large differences in acoustic impedance and significant energy reflection, which is not conducive to high-fidelity tactile restoration. Therefore, from the perspective of acoustic impedance matching, the advantages of carbon fiber in tactile music conduction can be explained.

In summary, the low-frequency vibration-conducting tactile feedback technology based on carbon fiber materials can significantly improve the musical experience of individuals with hearing impairment. Through tactile feedback, they can reperceive music rhythm, pitch, and emotional changes, and even generate emotional arousal responses. Future research should continue to optimize materials and devices, broadening their use in other application scenarios and providing new avenues for music perception for more individuals with hearing impairment.

The frequency response range of the human tactile system is limited by the skin and the nervous system, especially in the high-frequency band (>2 kHz), where the skin's ability to perceive mechanical vibrations significantly declines. Studies have shown that high-frequency vibration stimulation has a relatively weak perceptual response on the skin and may not be able to activate sufficient neural signals to effectively transmit information. Although materials such as carbon fiber perform well in the low-frequency range, their perception ability in the high-frequency range is still affected by physiological limits.

CONCLUSION

As the demand for musical experiences among individuals with auditory impairments increases, existing music devices gradually fail to meet the diverse needs of various populations. This study explored fiber materials as tactile transmission media, aiming to enhance the music perception experiences of individuals with hearing impairment through vibration-conducting technology. The results indicate that carbon fiber exhibits the highest vibration-conducting efficiency in the low-frequency range, reaching 4.85 m/s^2, which is superior to nylon and polyester. The participants' tactile recognition rate for low-frequency music was 92%, whereas that for high-frequency music was only 43%. For the hearing-impaired group, rhythm perception accuracy improved to 85.2% with carbon fiber materials, approaching the 89.3% of the normal hearing control group. Additionally, carbon fiber materials can significantly increase the emotional arousal intensity of individuals with hearing impairment, with skin conductance response values increasing by 35%. Although the results demonstrate the excellent performance of carbon fiber in low-frequency vibration transmission, the tactile recognition rate for high-frequency music remains low. Future research can optimize material structures and frequency response ranges to enhance tactile perception effects for high-frequency music. This study provides new avenues for music perception for individuals with hearing impairment.

Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

Author Contributions

Jing Wen and Zhao Chen designed the study; all authors conducted the study; Siyu Wang and Jing Wen collected and analyzed the data. Siyu Wang and Zhao Chen participated in drafting the manuscript, and all authors contributed to critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, took public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work were appropriately investigated and resolved.

Ethics Approval and Consent to Participate

This survey was conducted in compliance with Ethics Committee of Hebei Petroleum University of Technology. Participants were informed of the study's purpose and data usage prior to participation, and responses were collected anonymously. No personally identifiable information was stored.

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Conflict of Interest

The authors declare no conflict of interest.

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