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RESEARCH ARTICLE

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Preliminary study on the characteristics of tactility of wood by physiological index HRV

Abstract We used heart rate variability (HRV), an electrophysiological index, to investigate the changes of the sympathetic and parasympathetic nervous systems of people when they were in contact with wood and other materials, in a time-domain, a frequency-domain, and by means of nonlinear dynamics. Our aim was to discover the relations among thermal parameters of different kinds of material, human physiological feedbacks, and psychological perceptions. It shows that the activity of the sympathetic nervous system when in contact with wood increased no more than when in contact with metal and ceramic materials, while the activity of the parasympathetic nervous system weakened less than when in contact with these materials. The time taken by the sympathetic and parasympathetic nervous systems to revert to their normal state after contact with cloth and wood was shorter than that after contact with metal and ceramic. A subjective survey, by SD method, showed that the tactility of wood was favorable and people preferred wood to other kinds of material. Correlation analysis' results showed that there was a close correlation among the HRV indices, human psychological emotion ratings, and thermal parameters of the different kinds of materials. The experiment proves that the effect of wood on our autonomous nervous system is slightly better than that of other materials except for cloth. Wood does not damage people's health.

Keywords wood, tactility, heart rate variability, physiology

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1 Introduction

According to Schachter's three-factor theory, the environment (including all kinds of materials), psychology, and physiology of people should be considered as an organic integral, in which these factors behave in an interactive and concerted effort. In such a system, the environment as the inducement can arouse physiological and psychological changes in people and, at the same time, humans can return an adjusting signal to the environment for seeking a free and comfortable bodily feeling, which constitutes a positive feedback chain. Therefore, we designed the physiological feedback experiment to study the physiological and psychological changes in people while touching various types of material and then discuss the inner relations among material factors and human physiological indices as well as psychological feelings, which can provide theoretical instructions for the design of comfortable and healthy surroundings.

Modern physiology indicates that, whether people's physiology is normal or not, it is closely related to the function of the autonomous nervous system. The autonomous nervous system includes the sympathetic and parasympathetic nervous systems. A sympathetic stimulus is related to reactions from the body, which can accelerate metabolism and provide energy when facing a threat, fleeing in an urgent situation, or when being excited. The function of the parasympathetic nervous system is to conserve energy and to slow down bodily reactions, which can be beneficial for rest and relaxation. Under normal conditions, to meet physiological needs, excitement and suppression always keep a dynamic balance in the body under the coordinated control of sympathetic and parasympathetic nervous systems. Our regular heartbeat changes moderately in accordance with this kind of dynamic balance, which is usually called heart rate variability (HRV) in medical circles. HRV is the fluctuation of the heart rate around its baseline and its variation of consecutive R-wave (RR) intervals. A quantitative analysis of HRV can reflect conditions of the autonomous nervous system, whether partly or entirely in balance.

At present, HRV has many advantages, such as abundant information, a noninvasive examination, a quantitative assessment of the autonomous nervous system, and so on, which is the reason for its wide application in medical engineering practices (Hou and Hua, 2001).

Research in the area of wood in the immediate surrounding, concerned with measuring physiological indices, is becoming popular in exploring the effect of wood and the wooden environment on human physiology, in which HRV is also applied as an important index. For example, Miyazaki (1998) advanced the idea of the coefficient of variation of cardiographic RR intervals to evaluate the physiological effect of wood on people. It is a pity that HRV indices were not analyzed more intensively.

In this paper, we describe an experiment in which we carried out an HRV analysis to study the changes in the activity of the autonomous nervous system while people are in contact with wood.

2 Materials and methods

2.1 Experimental material and processes

The experiment was carried out in a condition-controlled laboratory, which was quiet, peaceful, and comfortable, with a room temperature of 20±1ºC without light, sound, and electromagnetic wave disturbance. The subjects for this experiment were 20 undergraduate students, whose average age was 23±2 years. All subjects were healthy and had no history of cardiogenic and neuropathic diseases. Before the test, all felt well, neither hungry nor fully satisfied.

We used a RM6280C Multi-channel Physiology meter manufactured by the Chinese Chengdu Instrument Factory to measure the electrical signals of heart rate. The electrodes were placed according to standard type II cardiographical tests.

Experiments can be started when the subjects have had five minutes rest and their heartbeat has been steady. All influences such as exciting conversation, deep breath, intense movement, and smoking should be avoided during the test period.

In our experiment, we first recorded the electrocardiogram signals of the subjects in a peaceful state as reference, and then recorded the electrocardiogram signals when their hands touched cloth, wood, plastic, ceramic, and metal. The recording time of each test was not less than 300 s. After the experiments, we used professional computer software, HRV analysis software designed by Kuopio University in Finland, to deal with the data and to analyze the effect of touching different materials on HRV.

We adopted a semantic differential (SD) method to investigate subjective feeling and measured the thermal parameters of the material touched by our subjects.

2.2 The mathematical analyses of HRV

The mathematical analyses of HRV are still under development. The analyses reported in the literature and their defined indices are diverse in nature. For the sake of selecting a criterion, this paper would follow the suggestion of the European Society of Cardiology, the North American Society of Pacing and Electro physiology (1996), and the HRV strategy group of the editorial board of the *Chinese Journal of Cardiology*. We applied time domain, frequency domain, and nonlinear dynamical analyses in this study and introduced corresponding indices to analyze the data (Xu et al., 1995; Sun and Bai, 2001).

2.2.1 Time domain analysis

The purpose of the time-domain analysis is to measure variables in the time series interval data between each two adjacent R waves. Statistical indices include the following: mRR (mean of RR intervals), SDNN (standard deviation of RR intervals), mHR (mean of heart rates), SDHR (standard deviation of heart rates), RMSSD (mean square root of standard deviation of RR intervals), PNN50 (heart impulses of RR intervals (>50 ms) as a percentage of the total), and HRVI (HRV index, the percentage of the total amount of RR intervals to the predominant RR intervals)

Among these indices, SDNN, RMSSD, PNN50, and HRVI are the most important as far as reflecting HRV is concerned.

2.2.2 Frequency domain analysis

Frequency domain analysis is used to transform the time series data of RR intervals into a frequency spectrum and to compute a power spectral density, which provides information of energy distribution along with frequencies. An autoregressive model (AR) and a Fast Fourier Transform (FFT) are commonly used methods for computing power spectra. Their advantage is that they obtain quantitative measurements of the activity of the autonomous nervous system by frequency, which supplements the shortcomings of the time-domain analysis method.

A power spectrogram can be obtained by frequency transformation and computation, with frequency as the X-coordinate (Hz) and power spectral density as the Y-coordinate (ms^2/Hz). There are three peaks in the power spectrogram. The first peak is located near 0.04 Hz, the second at 0.1 Hz, and the third at 0.25 Hz. Within this range, the spectrogram can be divided into three frequency bands that reflect some physiological activity.

In the very low frequency (VLF) band, the frequency ranges from 0.003,3 to 0.04 Hz. It reflects the regular diurnal variation under the dual influence of the sympathetic and parasympathetic nervous systems. It is correlated with the change of blood vessel impedance and heat regulation.

In the low frequency (LF) band, the frequency ranges from 0.04 to 0.15 Hz. It reflects the average power of low frequency of sympathetic tension under the dual influence of the sympathetic and parasympathetic nervous systems. It may provide information about blood pressure. The increase in LF values reflects the activity of the ascendant sympathetic nervous system, which may be caused by a change in body posture, a nervous reaction, a decrease in the barometric pressure, and so on.

In the high frequency (HF) band the frequency ranges from 0.15 to 0.40 Hz. It reflects the average power of high frequency of parasympathetic tension. High frequency is correlated with breath frequency (r>0.8).

On the whole, the HF and LF bands of the HRV spectrum can both better reflect the activities of the sympathetic and parasympathetic nervous systems and the (LF/HF) ratio is used as a major index to express the change in the parasympathetic nervous system as well as the balance between the sympathetic and parasympathetic nervous systems.

2.2.3 Nonlinear dynamical analysis

In time- and frequency-domain analyses, not only is the overall variation of heart rate measured but the instantaneous change in heart rates is also covered. A nonlinear dynamic analysis can reflect the instantaneous change in heart rates. The nonlinear, dynamic characteristics of data can be expressed by scatter point diagrams, which are also called Poincaré plots. Poincaré plots contain trends of linear and nonlinear changes in HRV and denote the condition of the autonomous nervous system. Recently, the use of Poincaré plots has been approved in medical circles.

We used the former RR interval of every two adjacent RR intervals as the X-coordinate and the latter as the Y-coordinate to draw Poincaré plots. In the diagram, all scattered points are distributed along a straight line at an angle of 45º. The length along the 45º direction indicates the average heart rate change, which is affected by the combined sympathetic and parasympathetic nervous systems. The width perpendicular to the 45º direction reflects the instantaneous change in heart rate related to the parasympathetic nervous system. When sympathetic tension increases, the heart rate increases quickly, the RR intervals reduce, and the scatter points approach the origin. When parasympathetic tension increases, scatter points become more distant from the origin. A Poincaré plot of normal people looks like an ellipse.

In our analyses, we used the vector length index (VLI) to measure the length of RR intervals, the vector width index (VWI) to measure the extent of scatter of RR intervals, and the vector angle index (VAI) to calculate the angle to the 45º line.

3 Results and discussion

3.1 Properties of material

We measured the thermal variables of various materials and the sense of warmth/coldness of our subjects (Table 1). The results indicate that differences in psychological feeling and the physiological changes in the body were affected by the density, thermal conductivity, heat flux density of the material touched, and so on.

Table 1 Thermal parameters of various materials and warmth/coldness sense of subjects

Material	Density/($kg \cdot m^{-3}$)	Thermal conductivity /($W \cdot m^{-1} \cdot K^{-1}$)	Heat flux density/($W \cdot m^{-2}$)	Maximum decline of skin temperature during test/ºC	Temperature change at the end of test/ºC	Warmth/coldness sense
Cloth	220	0.08	93.74	0.9	0.7	4.13
Wood	550	0.15	141.91	1.6	0.4	3.72
Fiberboard	600	0.15	138.90	1.7	0.2	3.50
Particle board	630	0.14	135.04	1.5	–0.1	3.61
Plywood	700	0.12	124.74	1.4	0.1	3.53
Epoxy resins	1180	0.38	155.23	1.9	–0.5	2.89
Plastic board	1760	0.66	170.37	2.4	–0.7	2.53
Concrete	2050	1.43	174.32	2.9	–1.2	2.23
Ceramic	2130	3.48	181.71	3.7	–1.6	1.87
Marble	2690	3.90	187.36	4.1	–1.9	1.67
Steel	7710	48	238.23	4.7	–2.2	1.33
Aluminum	2640	179	317.79	5.1	–2.5	1.09

Criterion of rating warmth/coldness sense: very cold (0–1); cold (1–2); a bit cold (2–3); moderate (3–4); warm (4–5).

3.2 Temperature changes of skin in contact with different materials

The changes in skin temperature during the tests were monitored by a noncontact infrared thermometer. The experimental results indicate that the maximum decline in skin temperature appeared within 30 s of making contact with the material; the temperature gradually rose over the period from 30 to 60 s and in the period from 60 to 300 s, the skin temperature became stable. It can be concluded from Fig. 1 that we should emphasize the period from 0 to 60 s.

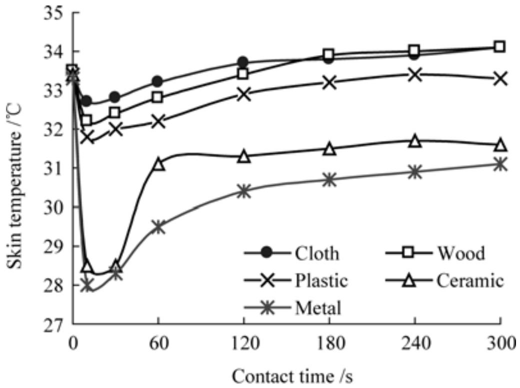

Fig. 1 Changes of skin temperature during test

3.3 Investigation of subjective feeling

According to investigations of subjective feelings, our mental sense of contact with various kinds of material differs before touching them. The feelings are of the type "would like to" or "gladly" and "no problem" when touching cloth and wood. When touching ceramic and metal, a feeling of "would rather not" or "dislike", or "stress" comes to the mind. These feelings may be attributed to psychological factors, cultural background, and a conditioned reflex formed from experience.

In our experiment, during the first 30 s after touching wood and plastic, there was a feeling of "a bit cold" or "cold", but not a physiologically uncomfortable feeling, while the feeling on touching ceramic and metal was one of "very cold" and "eager to leave" with a slightly uncomfortable sense. In the period from 30 to 60 s after contact, the "cold" feeling to cloth, wood, and plastic disappeared gradually, but persisted in ceramic and metal, although it decreased somewhat. In the period from 60 to 300 s, the "cold" feeling decreased continuously but persisted in ceramic and metal and, at the same time, there was a sense of pain in the palm, while there was stable and peaceful feeling while in contact with cloth and wood. The results of the rate of warmth or coldness of the various kinds of material by the SD method are shown in Table 1. The relationships between a contact sense of warmth or coldness and the logarithm of thermal conductivity (λ) of the material are shown in Fig. 2.

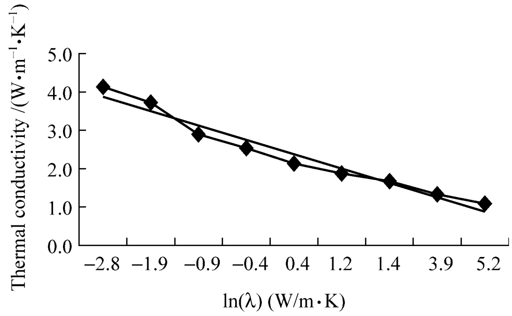

Fig. 2 Relation between warmth/coldness sense and thermal conductivity

3.4 Time-domain analysis of HRV

According to the time domain indices of HRV in Table 2, the values of mHR were larger than normal, which indicated an increase in the heart rate when in contact with the material. The values of mRR and SDNN of various materials were lower than normal, while values of RMSSD, PNN50, and HRVI were higher than normal. This indicated that sympathetic tensions increased, parasympathetic activity decreased, and the condition of the autonomous nervous system changed little, which might have been caused by temperature differences and heat transfer between skin and material. All of the indices, mentioned above, of touching cloth and wood changed little, which demonstrates that the stimulus of cloth and wood is lower than that of ceramic and metal.

Table 2 Time domain indices of HRV when touching different materials

	mHR /min^{-1}	mRR /ms	SDNN /ms	RMSSD /ms	PNN50 /%	HRVI
Normal	70.39	852	39	37.3	8.4	28.82
Cloth	70.83	837	35	35.2	7.6	27.93
Timber	71.59	828	32	33.5	6.8	27.03
Plastic	72.37	821	30	31.2	6.3	26.36
Ceramic	72.90	813	27	29.1	5.5	24.92
Metal	74.34	807	25	28.2	5.0	22.19

Normal values obtained from subjects when not in contact with anything.

3.5 Frequency domain analysis of HRV

From frequency domain indices of HRV in Table 3, it can be seen that TP, VLF, LF, LF/HF, and (VLF+LF)/HF indices of touching various materials all increased, while the HF index decreased a little, which indicated that a sympathetic activity was in ascendance, a parasympathetic activity weakened, and the activity of the autonomous nervous system enhanced. This might have been caused by the heat exchange between humans and material. Energy metabolism increased and, at the same time, the spirit became alert.

3.6 Nonlinear analysis of HRV

It can be seen from Fig. 3 that much variation occurred when touching different materials, including an increase in the length axis, a reduction in the width axis, and the head of scattered points approaching the origin, compared with the normal state. All this intuitional variation showed that touching materials causes sympathetic activities to increase and parasympathetic activities to decrease.

3.7 Analysis of HRV from different time segments

The entire test process was divided into five time segments and every time segment was 60 s long. We adopted HRVI to describe HRV and the activity of the autonomous nervous system in different time segments. It can be seen that the

Table 3 Frequency domain indices of HRV when in contact with different materials

	TP	VLF	LF		HF		LF/HF	VLF+LF/ HF
	/(ms^2·Hz^{-1})	/(ms^2·Hz^{-1})	/(ms^2·Hz^{-1})	/%	/(ms^2·Hz^{-1})	/%		
Normal	3,287	1,664	983	24.0	640	76.0	1.536	3.979
Cloth	4,614	2,963	1,011	29.1	630	70.8	1.604	6.308
Timber	5,279	3,608	1,074	30.5	617	69.5	1.741	7.588
Plastic	5,997	4,297	1,102	33.2	598	66.8	1.841	9.028
Ceramic	6,643	4,882	1,214	39.4	547	60.6	2.219	11.146
Metal	7,501	5,731	1,297	43.1	473	56.9	2.742	14.858

Normal values obtained from subjects when not in contact with anything.

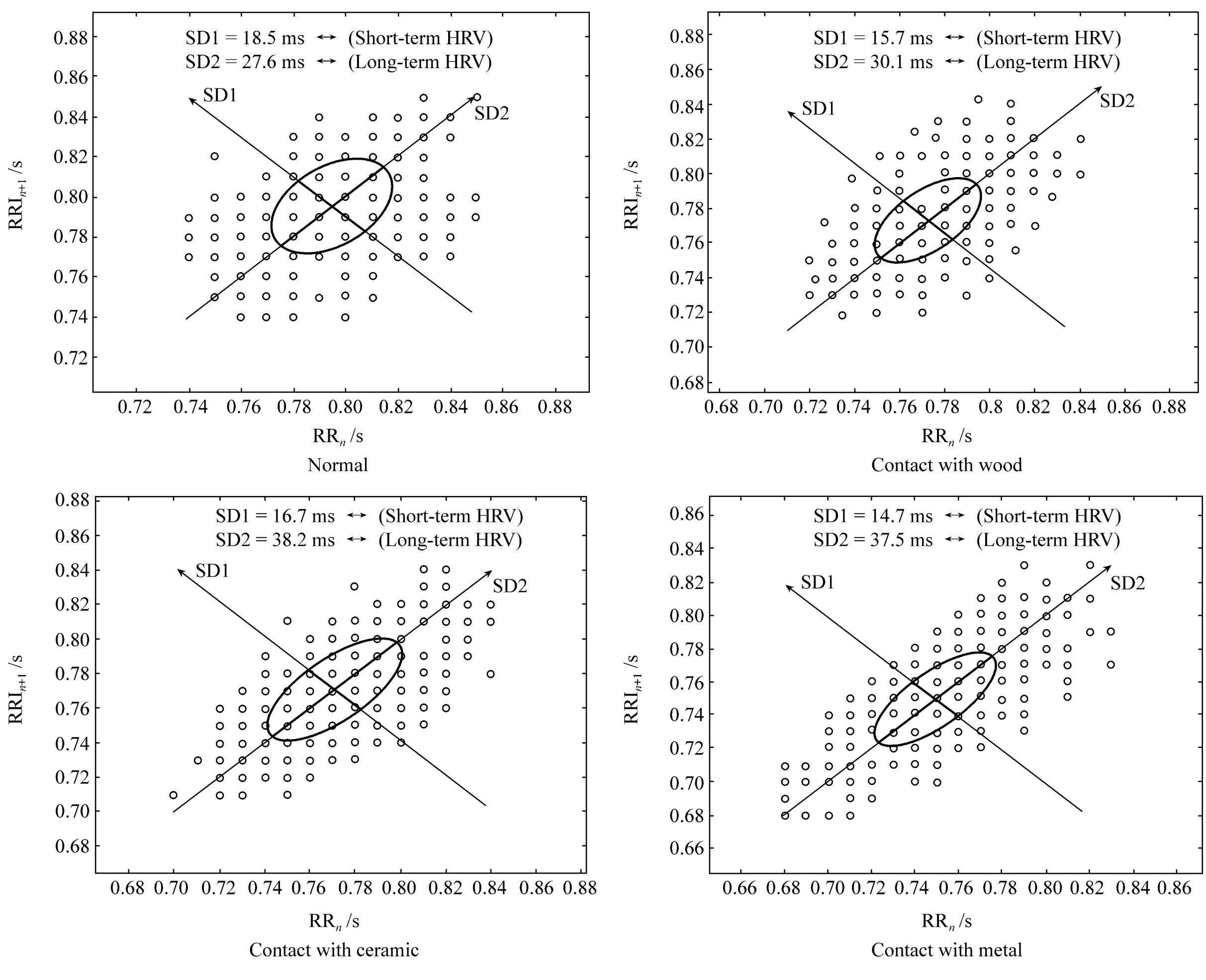

Fig. 3 Poincaré plots of HRV when in contact with materials Normal values obtained from subjects when not in contact with anything

changes of HRVI of different materials differ in different segments. The maximum declines of HRVI when in contact with cloth, wood, and plastic were in the range from 3% to 10%, while they were much higher when touching ceramic and metal. These ranged from 15% to 25%. The HRVI values of touching cloth and wood in the end approached 110%, while they could only approach about 90% when in contact with plastic, ceramic, and metal. Therefore, we can conclude that contact with cloth and wood has little influence on the balance of the autonomous nervous system, and the parasympathetic nervous system could be quickly restored or can even exceed the normal level and enable humans to feel safe and comfortable.

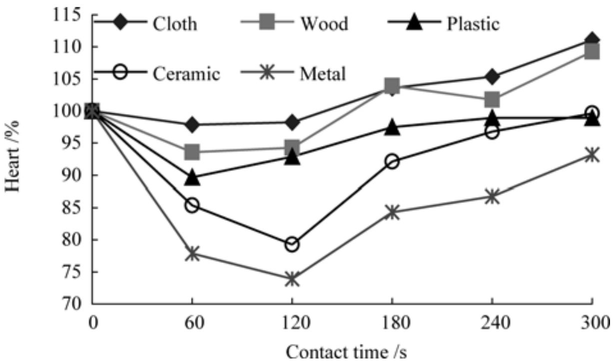

Fig. 4 Changes in HRVI during different time segments when in contact with different materials

4 Conclusion

It can be concluded that the tactility of wood is affected not only by its properties but also by our physiological defense mechanism and psychological background. Only through exhaustive analysis and consideration, can we explain with some authority the common cognition that "the tactility of wood and cloth is superior to that of plastic, ceramic, and metal".

The study also shows that application of experimental techniques of physiology and the psycho-physiological theory in wood science research would be helpful in promoting the acceptance and development of wood science from a novel point of view.

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