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Experimental Study on the Response of Hand-Transmitted Vibration from an EVA Power Tool

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Abstract: The objective of this paper is to accurately measure the vibration response of tools and hands by simulating the hand-held power tools, which are operated by astronauts wearing extravehicular spacesuit gloves under microgravity conditions. The total vibration value and the daily vibration exposure of the subject's hand are obtained. The results show that the opisthenar is more sensitive to the vibration frequency less than 200 Hz. After frequency weighting, the vibration exposure in the composite state of wearing an unpressurized spacesuit glove on the opisthenar is 23.6% greater than the vibration exposure of the palm, and for the bare hand, the percentage is 25.1% under the same condition. Because the operation time of tightening a screw is longer than that of loosening, the tightening operation performed by wearing spacesuit gloves produces 15.7% more mean vibration exposure on the palm and opisthenar than the loosening operation. The results of vibration transmissibility characterized by the total vibration weighted method and the total vibration unweighted method are 0.039 and 0.094, respectively. In comparison with bare hands, the mean daily vibration exposure on the palm and opisthenar in the composite state by wearing spacesuit gloves is 16.3% less, indicating that the unpressurized spacesuit gloves have an effect on vibration reduction. The research reveals the law of hand-transmitted vibration caused by the coupling of the extravehicular activities (EVA) power tools and spacesuit gloves, and provides a novel method for further similar tests and verification of hand-held EVA power tools.

Keywords: EVA power tool; hand-transmitted vibration; daily vibration exposure; vibration transmissibility; assembly

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1. Introduction

In manned on-orbit maintenance tasks, astronauts must wear bulky extravehicular spacesuits to resist the threats posed by vacuum, temperature alternating, cosmic radiation and micrometeoroids, and use hand-held EVA power tools to repair or replace faulty instruments and equipment.Astronauts in the International Space Station need to remove and install dozens to hundreds of screws when performing an on-orbit maintenance mission using EVA power tools [1–3]. The movement ability of astronauts' arm muscles could be reduced by more than 10%, which is affected by environmental factors such as microgravity and temperature alternation [4]. Simultaneously, due to the constraints of the extravehicular spacesuit on the motion ability, when the same vibration magnitude is generated by a power tool, on-orbit operations are more likely to cause astronaut fatigue than ground conventional operations, resulting in a decrease in arm strength, flexibility, range of motion, and operation accuracy [5]. Many researchers have carried out in-depth research on the measurement and evaluation methods, biodynamic responses and mechanical-equivalent models of hand-transmitted vibration. Burström et al. [6] compared the differences between three vibration exposure assessment methods. Xu et al. [7] developed a method for evaluating vibration-reducing gloves and determined the impact of these gloves on vibration

exposure. Marchetti et al. [8] studied the relation between the vibration transmissibility of the human elbow joint along the forearm direction and the grip strength. Vergara et al. [9] measured hand-transmitted vibrations generated by 70 power tools used in different industrial sectors. Lindenmann et al. [10] measured the influence of different body postures, feed force, and gripping force on the vibration of hand-held tools. Dewangan et al. [11] tested the vibration total value of hand-transmitted vibration at different forward speeds and different vibration directions under different operational modes of a hand tractor. Dong et al. [12–15] studied in depth the multi-degrees-of-freedom models of the arm system based on a two-point coupling approach to characterize the biodynamic response of human body substructures to vibration.

At present, most of the studies carried out in relevant fields are on the hand-transmitted vibration generated by using ground power tools with bare hands or wearing vibration-reducing gloves and vibration suppression. However, there are few results on the hand-transmitted vibration of EVA power tools used by astronauts wearing extravehicular spacesuits. With the further improvement of the mission complexity and operation refinement requirements of EVA, higher requirements are put forward for the hand-transmitted vibration control of power tools. Therefore, the methods of vibration control and its ergonomic characteristics based on spacesuit gloves and EVA power tools need to be deeply studied. This paper uses the measurement and evaluation method of hand-transmitted vibration in ISO 5349-1:2001. The vibration total value and the daily vibration exposure are used as evaluation indexes. A ground test device is built to simulate the astronauts' disassembly and assembly of screws in EVA to obtain the vibration response of astronauts' hands, which provides ideas and methods for the test and verification of EVA power tools.

2. Theoretical Consideration

Based on the mission requirements of on-orbit maintenance of China's space station, a Pistol Power Tool (PPT) for astronauts wearing spacesuits to operate is developed. When using this pistol-type power tool (hereinafter referred to as the power tool), astronauts need to hold the tool handle with one hand and keep the forearm parallel to its output shaft, and then pull the trigger with their fingers to keep the output shaft rotating. The vibration generated by the motor is finally transmitted to the hand through the ontology and handle structure of the tool. The transmission path of vibration contains multiple directions, which can be equivalent to the synergy of three orthogonal directions of the X_h-axis, Y_h-axis, and Z_h-axis in theory.

The origin of the biodynamic coordinate system is defined as the head of the third metacarpal (distal extremity) according to the definition of the basicentric coordinate system of hand-transmitted vibration in ISO 5349-1:2001. The Z_h-axis is defined as the longitudinal axis of the third metacarpal bone, pointing to the distal end of the finger of the unfolded palm. The Y_h-axis crosses the origin, parallels the axis of the power tool handle and points to the thumb direction. The X_h-axis is perpendicular to the Z_h-axis and the Y_h-axis through the origin, which is defined as perpendicular to the longitudinal axis of the third metacarpal bone and pointing from the hand to the power tool handle, as shown in Figure 1. In this test, the vibration total value a_{hv} of frequency-weighted r·m·s acceleration and 8-h energy-equivalent frequency-weighted vibration total value $A(8)$ are used as the evaluation indexes to show the influence degree of hand-transmitted vibration to the human hand system.

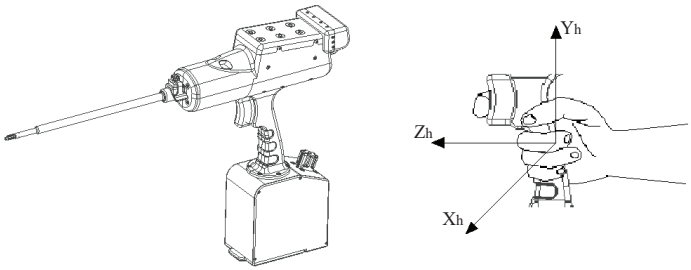


Figure 1. The biodynamic coordinate system of PPT.

Because the response of hand-transmitted vibration for the human body varies greatly in different frequency ranges, frequency-weighted r·m·s acceleration values are used to describe the human body's perception of vibration intensity. Its calculation is shown in Equation (1):

$$a_{hw} = \sqrt{\sum_i (W_{hi} a_{hi})^2} \tag{1}$$

where a_{hw} is the frequency-weighted r·m·s single-axis acceleration value (m/s^2); and W_{hi} is the weighting factor for the i-th one-third-octave band (W_{hi} comes from in Appendix A of ISO5349-1:2001); and a_{hi} is the r·m·s acceleration measured in the i-th one-third-octave band (m/s^2).

The acceleration magnitude is expressed by the vibration total value. Its calculation is shown in Equation (2):

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \tag{2}$$

where a_{hv} is the vibration total value of frequency-weighted r·m·s acceleration (m/s^2); a_{hwx}, a_{hwy}, and a_{hwz} are the frequency-weighted r·m·s single-axis acceleration values in the three axes, respectively (m/s^2).

Furthermore, 8-h energy-equivalent vibration total value $A(8)$ (hereinafter referred to as the daily vibration exposure) is used to compare the vibration exposure at different durations. Its calculation is shown in Equation (3):

$$A(8) = \sqrt{\frac{1}{T_0} \sum_{i=1}^{n} a_{hvi}^2 T_i} \tag{3}$$

where a_{hvi} is the vibration total value for the i-th operation (m/s^2); and n is the number of individual vibration exposures; and T_0 is the reference time 28,800 s; and T_i is the duration of the i-th operation (s).

The total vibration weighted method [16] and the total vibration unweighted method [17] are used to characterize the vibration transmissibility. The difference between the two methods is that the total vibration weighted method characterizes the vibration intensity actually perceived by the hand, while the total vibration unweighted method characterizes the vibration intensity generated by the tool reaching the hand. Two methods are used to evaluate the influence of the spacesuit glove on vibration transmission characteristics. The vibration transmissibility is defined as the ratio of the vibration total value of the palm to the vibration total value of the handle. Its calculation is shown in Equations (4) and (5):

$$MT = \frac{\sqrt{a_{pwx}^2 + a_{pwy}^2 + a_{pwz}^2}}{\sqrt{a_{hx}^2 + a_{hy}^2 + a_{hz}^2}} \tag{4}$$

$$TR = \frac{\sqrt{a_{px}^2 + a_{py}^2 + a_{pz}^2}}{\sqrt{a_{hx}^2 + a_{hy}^2 + a_{hz}^2}} \quad (5)$$

where MT and TR respectively represent the vibration transmissibility from the handle to the palm measured by the total vibration weighted method and the total vibration unweighted method; a_{pwx}, a_{pwy}, and a_{pwz} are the frequency-weighted r·m·s single-axis acceleration value measured at the palm wearing a spacesuit glove, respectively (m/s^2); a_{px}, a_{py}, and a_{pz} are the frequency-unweighted r·m·s single-axis acceleration value measured at the palm when wearing a spacesuit glove, respectively (m/s^2); a_{hx}, a_{hy}, and a_{hz} are the frequency-unweighted r·m·s single-axis acceleration value measured at the handle (m/s^2).

3. Materials and Methods

3.1. Test Procedure

A set of hand-transmitted vibration test devices of PPT is built. Three subjects skilled in operating this power tool tighten and loosen the M5 screws successively with the power tool equipped with operating rods of 200 mm, 300 mm, and 400 mm in length under the conditions of bare hands and wearing unpressurized spacesuit gloves, respectively. Three subjects conducted a total of 12 working condition tests and 70 groups of tests are completed under each working condition, as shown in Table 1.

Table 1. Twelve working conditions of the test.

Working Condition	Hand State	Length of Operating Rods	Operation
Condition 1	Gloved hand	200 mm	Tighten
Condition 2			Loosen
Condition 3		300 mm	Tighten
Condition 4			Loosen
Condition 5		400 mm	Tighten
Condition 6			Loosen
Condition 10	Bare hand	200 mm	Tighten
Condition 20			Loosen
Condition 30		300 mm	Tighten
Condition 40			Loosen
Condition 50		400 mm	Tighten
Condition 60			Loosen

3.2. Test Equipment

The hand-transmitted vibration test device includes PPT, a gravity balancer, a support group frame, screws, an extravehicular spacesuit glove, acceleration sensors, data collector, etc. The screws are installed on the support group frame to simulate on-orbit operation. In addition, PPT is suspended by the gravity balancer to simulate microgravity conditions. Then, the subjects operate the power tool with bare hands or wearing spacesuit gloves, as shown in Figure 2.

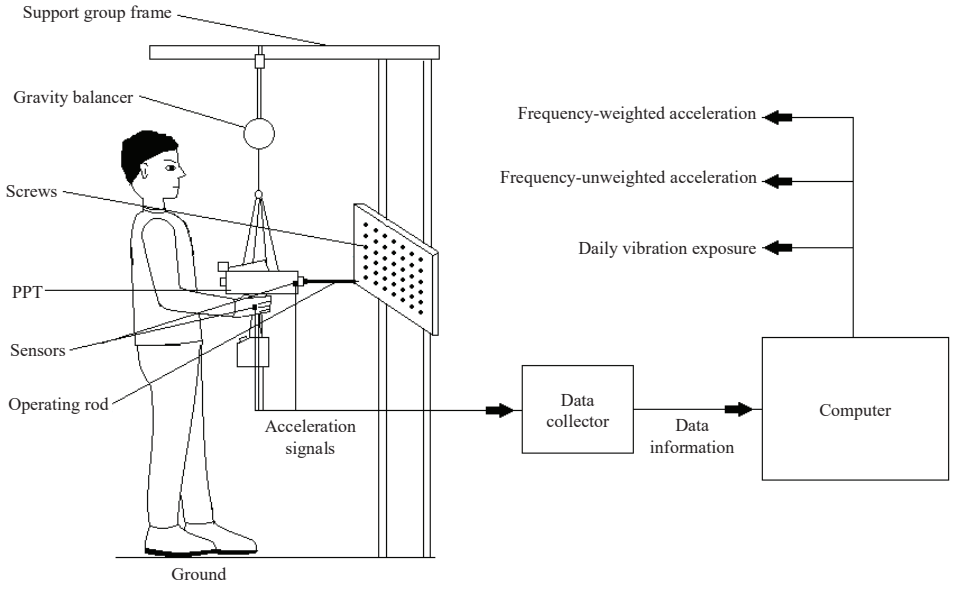


Figure 2. Typical subject posture for measuring biodynamic responses of the human hand.

3.3. Vibration Measurement

During the test, the indoor temperature is maintained at 20 °C∼25 °C, the ambient pressure is about 101 kPa, and the humidity is controlled at 40%∼60%. The height, weight, and other physiological characteristics of the three subjects are similar to those of astronauts. They are required to stand upright on the ground wearing regular overalls, and the palm of their right hand is attached to the right side of the power tool handle, and the forearm of the right hand is parallel to the direction of the output shaft. Their elbows cannot be in contact with the body, and the angle of the forearm and upper arm is controlled at 90°∼120° according to ISO 10819:2013. The test includes four measuring points: handle measuring point, output shaft measuring point, palm measuring point, and opisthenar measuring point. The positions of the measuring points are shown in Figure 3.

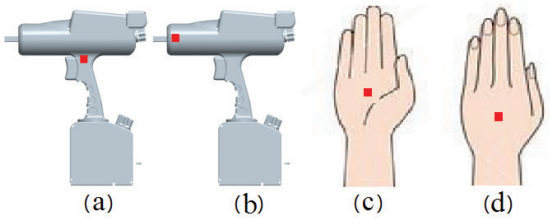


Figure 3. Location of acceleration sensors: (**a**) handle measuring point; (**b**) output shaft measuring point; (**c**) palm measuring point; and (**d**) opisthenar measuring point.

The fixed method of the hand measuring point sensors is to attach the sensors to the aluminum hand-held adapter and secure the adapter with a nylon cable tie. The fixed method of the tool measuring point sensors is to attach the aluminum-based tape to the tool measuring point plane, and then use adhesive to attach the sensors to the aluminum-based tape.

In addition, ensure that the three measurement directions of each acceleration sensor correspond to the X_h-axis, Y_h-axis, and Z_h-axis corresponding to the biodynamic coordinate system one by one [18]. When operating the power tool with bare hands, the subjects applied approximately equal grip force to make the sensor contact tightly with the handle and palm according to ISO 5349-2:2001. When operating the power tool with spacesuit gloves, as shown in Figure 4, the sensor contacts tightly with the glove and palm inside the spacesuit glove. Meanwhile, to reduce the influence of operating posture and environmental changes, the test of each working condition is completed continuously at one time.

After the test of each working condition is finished, the subject rests for 30 min to continue the next test.

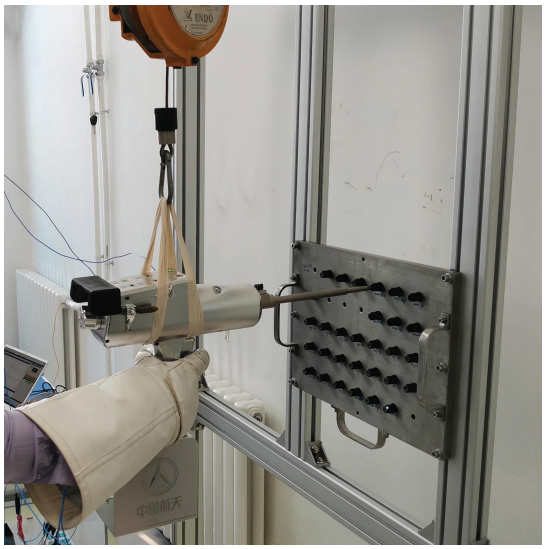


Figure 4. The typical subject operating test with spacesuit gloves.

3.4. Data Analysis

PCB356A16 three-axis accelerometers are used to obtain the 1/3 octave frequency-unweighted acceleration value of four measuring points in the range of 1 Hz∼1250 Hz on the X_h-axis, Y_h-axis, and Z_h-axis. Each group of acceleration signals is transmitted to the SCADAS mobile high-speed synchronous data collector, and the weighted method recommended by ISO 5349:2001 is used for filtering and storage, respectively. Based on the frequency-unweighted r·m·s acceleration value of the power tool and the frequency-weighted r·m·s acceleration value of the hand, the vibration total value and the daily vibration exposure of 6.3 Hz∼ 1250 Hz under each working condition are calculated.

4. Experimental Results

4.1. Vibration Characteristics in Different Operating States

During on-orbit maintenance, tightening and loosening screws are two different operating states. Considering these two states can affect hand-transmitted vibration characteristics, the vibration total value of the human hand is calculated by using Equations (1) and (2), as shown in Figure 5. It is shown that the vibration total value produced by tightening and loosening in each measuring point is very close, and the average error is 5.8%. The distribution of the vibration total value of the four measuring points of each operating rod is that the value of the output shaft measuring point is the maximum, the value of the handle ranks second, the value of opisthenar ranks third, and the value of the palm is the minimum. The vibration of the power tool comes from the motor and reducer, and the motor drives the casing vibration when the power tool is working. On the one hand, the motor vibration is transmitted to the output shaft. On the other hand, the casing vibration is transmitted to the handle, which generates forced vibration to the arm system through the handle. The data show that the vibration total value at the handle is lower than that of the output shaft. At first, it verifies the rationality of the configuration design of the power tool in terms of vibration transmission response. Secondly, the energy absorption of vibration caused by the damping formed by the palm thenar muscle and gloves leads to the attenuation of vibration at the handle.

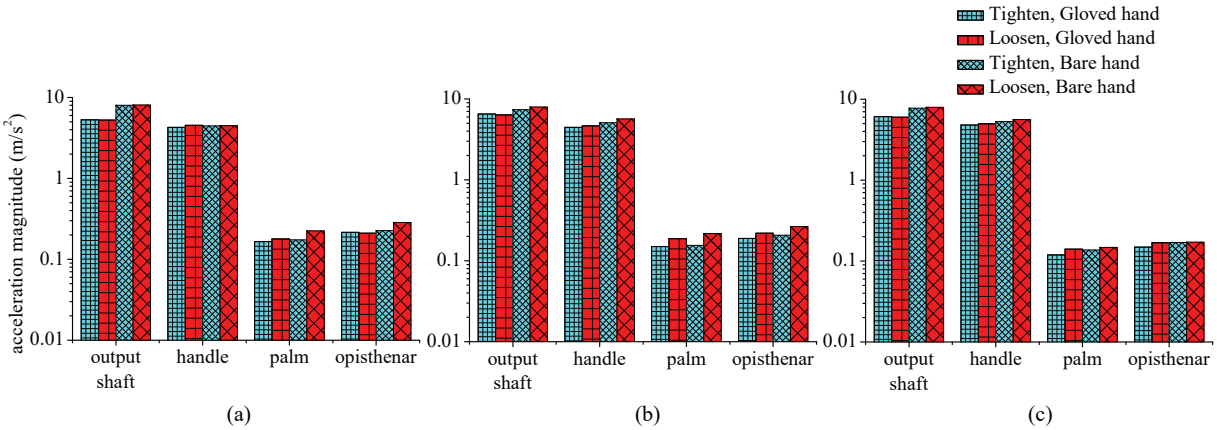


Figure 5. Comparison of mean vibration total value of four measuring points for PPT: (**a**) 400 mm operating rod; (**b**) 300 mm operating rod; and (**c**) 200 mm operating rod.

Considering that vibration exposure is the comprehensive effect of vibration total value and exposure time, Equation (3) is used to calculate the daily vibration exposure in tightening and loosening states. The composite state refers to the whole process including tightening and loosening. Assuming that t screws need to be tightened, the vibration total value and tightening time of the i-th tightening operation are recorded as a_{hvi} and T_i, respectively. Assuming that s screws need to be loosened, the vibration total value and loosening time of the k-th loosening operation are recorded as a_{hvk} and T_k, respectively. Therefore, the screws will be tightened and loosened t and s times respectively in the composite state, and the vibration total value and operation time of the c-th operation in the composite state are recorded as a_{hvc} and T_c, so the daily vibration exposure in the composite state is shown in Equation (6):

$$A(8)_c = \sqrt{\frac{1}{T_0}\sum_{c=1}^{t+s} a_{hvc}^2 T_c} \tag{6}$$

where $\sum_{c=1}^{t+s} a_{hvc}^2 T_c = \sum_{i=1}^{t} a_{hvi}^2 T_i + \sum_{k=t+1}^{t+s} a_{hvk}^2 T_k$. Therefore, the daily vibration exposure of the composite state can be characterized by the daily vibration exposure of tightening and loosening operations. Its calculation is shown in Equation (7):

$$A(8)_c = \sqrt{A(8)_t^2 + A(8)_s^2} \tag{7}$$

where $A(8)_c$, $A(8)_t$, and $A(8)_s$ represent the daily vibration exposure in the composite state, tightening, and loosening, respectively (m/s^2). The daily vibration exposure of three states when operating power tools with the spacesuit glove is shown in Figure 6. It can be shown that the daily vibration exposure of tightening is greater than that of loosening. Although tightening and loosening the screw are roughly the opposite processes, the average time spent tightening a screw is 7.15 s, which is greater than the average time of loosening a screw of 6.76 s in this test. Therefore, the cumulative exposure time is longer when the vibration total value is consistent basically, resulting in subjects bearing 15.7% more mean daily vibration exposure when tightening screws wearing spacesuit gloves.

Similar to the distribution law of the vibration total value, the daily vibration exposure of the opisthenar is greater than that of the palm in the three states. Taking a group of data of the tool with a 400 mm operating rod used with bare hands in this test as an example, the spectrogram before and after filtering of this group of tests is shown in Figure 7. In Figure 7a, the vibration total value of the palm and the opisthenar is 3.35 m/s^2 and 0.53 m/s^2, respectively. In the weighted signal shown in Figure 7b, the vibration total value of palm and the opisthenar are 0.23 m/s^2 and 0.27 m/s^2, respectively. It can be seen

from the figure that, on the X_h-axis and Y_h-axis, no matter whether the accelerometer is weighted or not, the opisthenar is more sensitive to low-frequency vibrations less than 200 Hz, while the palm is more sensitive to high frequency vibration greater than 200 Hz before the frequency is weighted. However, in the frequency-weighted curve recommended by international standards ISO 5349-1:2001, the low-frequency component of 8 Hz∼16 Hz is mainly considered. As a result, the high frequency components in each axial direction of the palm are greatly weakened, while the low frequency components in the opisthenar are mostly retained.

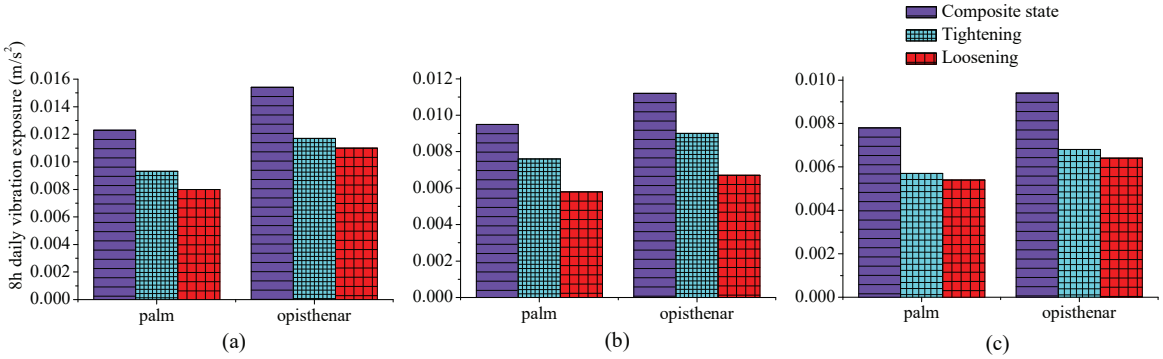
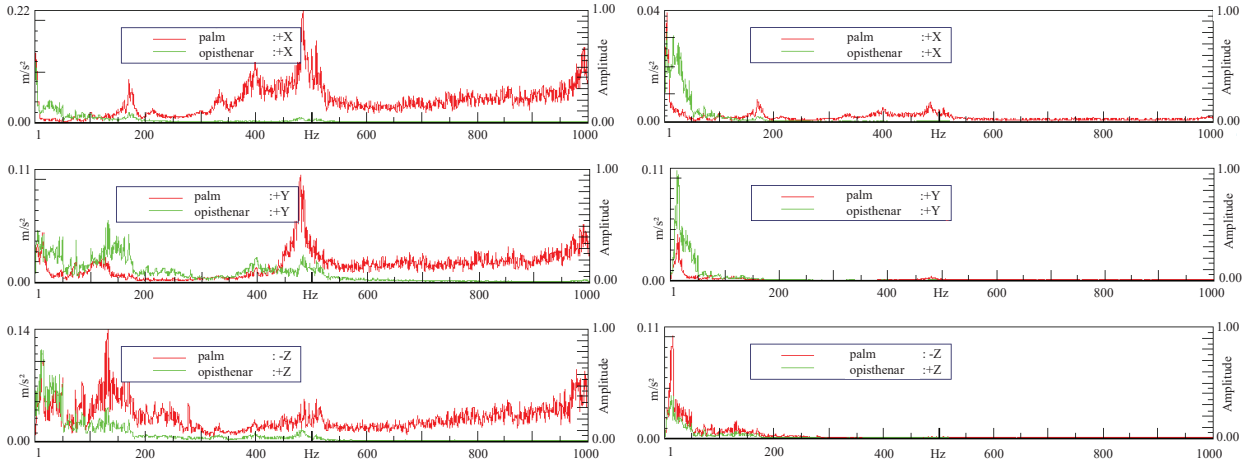


Figure 6. Comparison of the daily vibration exposure of the composite state, tightening and loosening wearing spacesuit glove: (**a**) 400 mm operating rod; (**b**) 300 mm operating rod; and a (**c**) 200 mm operating rod.



(**a**) before frequency weighting (**b**) after frequency weighting

Figure 7. Comparison of the three-axis test signals' filter spectrogram of the power tool using a 400 mm operating rod with bare hands.

Due to the palm and the opisthenar responding differently to the different frequency components, the daily vibration exposure at the opisthenar in the composite state of wearing the spacesuit glove is 23.6% larger than the measured value at the palm. The daily vibration exposure at the opisthenar in the composite state of the bare hand is 25.1% greater than the measured value at the palm.

4.2. Transmission Characteristics of Vibration

To analyze the influence of the spacesuit glove on vibration transmission, the test is carried out on bare hands and wearing spacesuit gloves. The results are shown in Table 2. The mean vibration total value in the tightening state and the mean daily vibration exposure in the composite state of wearing spacesuit gloves are 8.6% and 16.3% lower than those measured in bare hands, respectively. The vibration transmissibility of power

tools with 400 mm operating rod is calculated according to Equations (4) and (5). The vibration transmissibility calculated by the total vibration weighted method and the total vibration unweighted method are 0.039 and 0.094, respectively. It shows that the vibration transmission will be reduced observably when wearing the unpressurized spacesuit glove. It is considered that the multi-layer flexible material in the glove and the rubber layer on the surface of the glove has an effect on vibration reduction.

Table 2. Mean vibration total value of tightening and mean daily vibration exposure in composite state of power tool.

Mean Vibration Total Value (m/s^2)				**Mean Daily Vibration Exposure (m/s^2)**			
Operating Conditions		**Bare Hand**	**Gloved Hand**	**Operating Conditions**		**Bare Hand**	**Gloved Hand**
200 mm operating rod	Palm	0.137	0.119	200 mm operating rod	Palm	0.0105	0.0093
	Opisthenar	0.170	0.149		Opisthenar	0.0126	0.0110
300 mm operating rod	Palm	0.156	0.150	300 mm operating rod	Palm	0.0138	0.0112
	Opisthenar	0.208	0.189		Opisthenar	0.0174	0.0147
400 mm operating rod	Palm	0.174	0.165	400 mm operating rod	Palm	0.0144	0.0130
	Opisthenar	0.228	0.216		Opisthenar	0.0184	0.0157

As the number of tightening and loosening screws increases on-orbit maintenance, the exposure time of operating power tools will also increase accordingly. Taking the composite state of a 400 mm operating rod as an example, its vibration exposure changes with the number of tightening and loosening screws, as shown in Figure 8. It can be shown that the vibration exposure increases approximately as a power function. The difference in vibration exposure between the palm and the opisthenar has a tendency to widen.

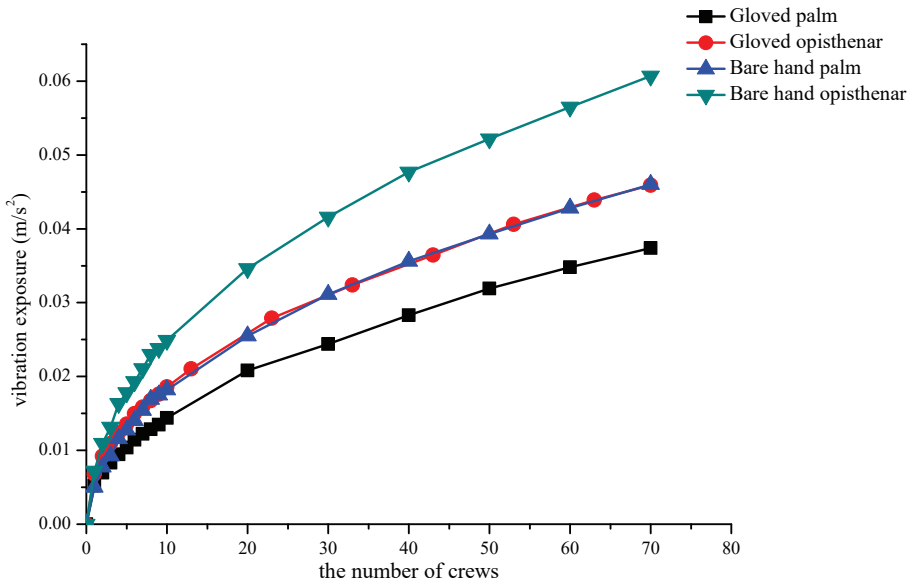


Figure 8. The vibration exposure in the composite state of a power tool using a 400 mm operating rod varies with the number of screws.

5. Discussion

5.1. Analysis of Test Results

Compared with the X_h-axis, there may be certain measurement uncertainty in the Z_h-axis and Y_h-axis in this test. The opisthenar is sensitive to low frequency vibration less than 200 Hz on the X_h-axis, Y_h-axis, and Z_h-axis when the frequency is not weighted. However, it is also noted that the palm also has a considerable response at about 140 Hz on the Z_h-axis. The

vibration of the tool is derived from the rotary motion of the motor rotor, whose axis is parallel to the Z_h-axis of the biodynamic coordinate system. Therefore, in the process of tightening and loosening screws, the vibration of Z_h-axis is restricted normally. The X_h-axis and Y_h-axis are the main vibration directions, which can more truly reflect the vibration caused by the power tool. However, the situation is more complicated on the Z_h-axis. On the one hand, Z_h-axis is perpendicular to the main vibration direction of the vibration source, and bears the vibration transmitted from the casing. On the other hand, the hand grip force, the push force of the palm, and the reaction force from screws may also affect the vibration. Otherwise, the lifting rope used in the test to overcome the gravity on the Y_h-axis will absorb part of the vibration energy, probably resulting in the vibration total value diminishing.

The total vibration weighted method based on the frequency weighting may overestimate the vibration damping performance of the spacesuit glove. In this test, the vibration transmissibility calculated by the total vibration weighted method and the total vibration unweighted method is 0.039 and 0.094, respectively, but the vibration transmissibility calculated by the total vibration weighted method is less than that calculated by the total vibration unweighted method. The total vibration weighted method characterizes the influence of the spacesuit glove on vibration transmission by frequency weighting. It is more concerned about the response of hand-transmitted vibration in the hand and highlights the human body's perception of vibration energy. The total vibration unweighted method describes the vibration reaching the human body without considering the real frequency attenuation caused by frequency weighting. The total vibration unweighted method more intuitively and clearly reflects the influence of the spacesuit glove, different frequency and other factors on hand-transmitted vibration.

5.2. Other Factors Affecting Measurement Uncertainty

This paper considers that the microgravity environment and the extravehicular spacesuit glove are the main factors affecting the response of hand-transmitted vibration except for the nature of the power tool itself. In the microgravity environment, it is more concerned about the operation posture of astronauts and the vibration caused by the tool itself. The structure of the spacesuit glove is complex, on the one hand, it limits the operation ability of the astronaut's hand [19,20], on the other hand, the special structure of the glove has the function of absorbing vibration. Therefore, the hand-transmitted vibration response of the spacesuit glove is complicated.

The unpressurized spacesuit glove used in this test may decrease measured vibration amplitude and vibration exposure. Because it is more flexible than the pressurized spacesuit glove, it may have a weakening effect on hand-transmitted vibration. In fact, the inner pressure of gloves after inflation of Chinese and American extravehicular spacesuits will reach 39.2 kPa and 29.6 kPa, respectively [21]. The stiffness of extravehicular spacesuit gloves increases after pressurization, which leads to the intensification of vibration transmission.

The gravity balancer in this test cannot accurately simulate the microgravity situation. The power tool is suspended through the flexible rope and the gravity balancer. It produces motion constraints on the power tool in the horizontal direction because of frictional resistance.

Factors such as the operating posture of the subjects also affect the measurement accuracy of the vibration response.

The actual environment of vacuum and temperature alternating in low Earth orbit (LEO) has little influence on the measurement of hand-transmitted vibration exposure. It may cause a little error in the measurement results if these parameters are not considered in the test.

5.3. Vibration Suppression of Power Tools

Vibration suppression can be carried out from three aspects: reducing vibration source intensity, optimizing transmission path, and reducing vibration response [22]. Based on the current, the motor with micro-vibration should be developed to reduce the intensity of the

vibration source of power tools. The dynamic performance of the motor should be improved by increasing the machining accuracy and assembly accuracy of parts. The vibration transmitted to the handle can be minimized by optimizing the overall configuration of the power tool, and selecting suitable casing and handle materials.

6. Conclusions

The vibration total value, the daily vibration exposure, and the vibration transmissibility have been used to characterize the response of hand-transmitted vibration of EVA power tool to human body in this paper. The effects of hand-transmitted vibration responses have been investigated in the tightening or loosening state, palm or opisthenar, bare hands, or wearing spacesuit gloves' conditions. The results show that subjects tightening screws with spacesuit gloves bear 15.7% more mean daily vibration exposure than loosening in the palm and opisthenar. The daily vibration exposure of the opisthenar is 23.6% greater than that of the palm in the composite state. In the composite state, the daily vibration exposure with spacesuit gloves is 16.3% less than the measured value of bare hands. It shows that unpressurized spacesuit gloves can alleviate hand-transmitted vibration to a certain extent. Both the total vibration weighted method and the total vibration unweighted method have been used to characterize the vibration transmissibility of spacesuit gloves. The results of these two methods are 0.039 and 0.094, respectively. The results show that the spacesuit glove has an obvious vibration absorption effect, but the total vibration weighted method may overestimate its vibration reduction performance.

In this paper, unpressurized spacesuit gloves are used and the microgravity environment is simulated, but the effects of pressurized spacesuit gloves and flexible rope on the test are not considered. These effects will be considered in further research.

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