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Investigation of materials for palm and dorsal of anti-vibration gloves for thermal comfort

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Abstract

The thermal comfort of a work glove affects wear compliance. This study investigates the thermal comfort of five types of anti-vibration gloves that use chloroprene rubber and spacer fabric as materials to isolate vibration. An evaluation of the fabric and material on the palm and dorsal of the glove, and a wear trial of the gloves were subsequently carried out. The results showed that the palm of the glove made of spacer fabric had higher air and water vapour permeabilities than chloroprene rubber. Using a thin mesh fabric for the dorsal of the glove resulted in a significantly lower skin temperature than using spacer fabric or chloroprene rubber during hand activity. The thermal sensation of the subjects showed no significant difference among the five glove samples. However, the glove wear comfort of the spacer fabric glove was the lowest. Recommendations for the fabric thickness and glove design are provided for developing anti-vibration gloves.

Keywords: Anti-vibration glove, Thermal comfort, Water vapour permeability, Air permeability, Spacer fabric, Glove-skin microclimate

Introduction

Many tasks in daily life are hand oriented and require protection. A variety of gloves are available to protect the hands during different tasks. In particular, anti-vibration gloves protect the hands during the use of electrical tools that emit vibrations, such as impact drivers, ballast tampers, chain saws, straight grinders, etc. (Hewitt et al., 2015, 2016). Prolonged exposure to the vibrations from electrical tools can numb the hand, affect blood circulation and injure the hand muscles and nerves (Brammer et al., 1987; Chetter et al., 1997; Chowdhry & Sethi, 2017; Gemne, 1997; Gerhardsson & Hagberg, 2014). In order to isolate the vibrations, anti-vibration gloves are designed with thick paddings on the palm to provide a physical barrier. Vibration isolation materials are typically chloroprene rubber, foam, urethane air bladders, resilient gel or a combination of these materials (Cabeças & Milho 2011; Dong et al., 2009; Md Rezali & Griffin 2016, 2017; Yu & Sukigara 2022). Chloroprene rubber is the most common vibration isolation material but is also thick and has low permeability. While this material is ideal for retaining thermal warmth in cold weather, when worn for a lengthy period of time for work will cause sweating of the hands. Heat and moisture are then trapped inside the glove, resulting in discomfort. This discomfort, together with the underestimation of the risk of using vibrating hand tools, can affect compliance with glove use and workers may choose to expose their hands to risk.

Some designs are adopted to enhance hand movement and dexterity with the use of anti-vibration gloves. For example, applying thicker vibration isolation materials onto parts of the glove that are most affected, such as the palm and the fingertips, or using thinner padding at the joints or elastic fabric at certain places on the glove. The protection against vibration is mainly focused on the palm side, where the hands are in contact with the vibrating hand tools. The dorsal of the anti-vibration glove is usually thinner and more elastic than the palm to allow hand movement with less effort. In order to reduce the perceived discomfort and increase finger dexterity, a fingerless anti-vibration glove is also available (Mas'aud & Abdullah 2015). However, there is a lack of studies on the features that can help to promote the thermal comfort of anti-vibration gloves. The design and use of materials for anti-vibration gloves differ from those for other types of work or protective gloves. However, few studies on the thermal properties of anti-vibration gloves can be found. It is crucial but challenging to fabricate a glove that offers optimal protection from vibration, and retains hand mobility, yet is also comfortable to wear.

Spacer fabric is commonly used for cushioning and pressure distribution purposes (Du et al., 2015). The knitted structure of spacer fabric can provide good air-permeability, and heat and moisture transfer abilities (Bagherzadeh et al., 2012; Chen et al., 2021; Liu & Hu 2011; Palani Rajan et al., 2021). Several studies have also confirmed the damping ability and the vibration isolation properties of spacer fabrics (Chen et al., 2016, 2018; Liu & Hu 2015; Taghvaie et al., 2020; Yu et al., 2020). Spacer fabric therefore has the potential to offer anti-vibration gloves with better comfort in terms of heat dispersion.

Yu and Sukigara (2022) examined the impact of an anti-vibration glove on hand dexterity and muscle activity. Apart from the dexterity performance, the wear comfort and thermal properties are other important aspects to consider in developing an anti-vibration glove. The wear comfort of the glove could affect wear compliance. The extra heat and discomfort given by the glove could affect the comfort sensation of the wearer, thus leading to poor wear compliance or affecting work performance. This study is an extension of Yu and Sukigara (2022) on anti-vibration gloves and aims to investigate the effect of different types of anti-vibration gloves made of different materials and designs on thermal comfort. Five types of anti-vibration gloves were investigated. The material properties of the palm and the fabrics of the dorsal of the gloves related to wear comfort, including thermal conductivity, air-permeability, and water vapour transmission, were evaluated. A wear trial experiment was also carried out to investigate the effect of the different types of anti-vibration gloves on the skin temperature and humidity of the hand and the subjective perception toward the gloves. The finding can help to act as a reference for choosing the materials and design to develop an anti-vibration glove with better wear comfort.

Methods

Glove samples

Five types of anti-vibration gloves were used in this study. Gloves 1 to 4 were purchased from the market, while Glove 5 was fabricated by using spacer fabrics. Details of the fabric used for the palm and dorsal side of the glove samples are presented in Table 1. All of the gloves were thicker on the palm side and thinner on the dorsal side. Gloves 1 to 4 used chloroprene rubber as the main material for isolating vibration. In order to facilitate hand movements, Glove 1 applied stitch lines at joints, Glove 2 made the chloroprene rubber into small rectangles and Glove 3 used a thin elastic fabric at the finger webs. On the other hand, the design of Glove 4 mainly focused on hand protection leading to a thick and heavy glove. For the wrist closure, Gloves 1 and 3 used velcro tapes, Glove 2 used a highly elastic rib fabric, while Glove 4 had a wide opening for easier donning and taking off. According to the information from the retailers, Gloves 1 and 2 were suitable to use for protecting hand from vibration and Gloves 3 and 4 were certified anti-vibration glove by ISO 10819:2013 and JIS-T8114:2007 respectively. The spacer fabrics used in Glove 5 were knitted by using a 10-gauge v-bed knitting machine (SWG091N210G, SHIMA SEIKI, Japan) with 100% 450D polyester yarn to create the plain knitted surface layers and 100% polyester monofilaments to form the connecting layer. Spacer fabrics with two different thicknesses were made by changing the tucking pattern of the connective yarn for the palm and dorsal of the gloves. The spacer fabric used on the palm showed vibration isolation ability over the frequency 28.8–1000 Hz when tested with ISO 13753, Method for measuring the vibration transmissibility of resilient materials when loaded by the hand-arm system (Yu et al., 2020). Glove 5 was made based on a basic glove pattern, and no special features were added to the design and wrist closure.

Objective evaluation of glove material properties

The palm and the dorsal of the glove samples were cut out to evaluate the properties. Three specimens were prepared for each side of each type of glove. All of the specimens were conditioned under standard conditions (temperature of 20 ℃ and relative humidity (RH) of 65%) for 24 h before testing in a conditioning chamber (IG400, Yamato Scientific Co., Ltd., Japan). The physical properties of the gloves related to thermal comfort were measured. The air permeability and thermal conductivity of the samples were evaluated based on the Kawabata fabric evaluation system.

The air permeability was measured by using a KES-F8-API air permeability tester (Kato Tech Co., Ltd., Japan). The amount of pressure that can be discharged and sucked through the fabric from a vent of 6.28 cm^2 was measured. The air resistance was calculated based on the difference between the pressure of the air chamber of the tester and the atmospheric pressure created by the fabric under a constant rate of airflow by using:

$$R = \Delta P/V \tag{1}$$

where R is the air resistance (kPa s/m), ΔP is the difference in pressure across the fabric between the air chamber of the tester and the atmosphere and V is the constant rate of the airflow.

Table 1 Details of glove samples

Glove	Dimension	Palm		Dorsal	
Glove 1	Wt: 36.66 g Wp: 904 g/m2 Wd: 260 g/m2 HL: 18.5 cm HC: 24.2 cm Tp: 4.82 mm Td: 1.16 mm	Artificial leather with patches of chloroprene rubber		Polyester knitted mesh fabric	
Glove 2	Wt: 91.02 g Wp: 2219 g/m2 Wd: 1055 g/m2 HL: 20 cm HC: 25.3 cm Tp: 6.63 mm Td: 2.62 mm	Nylon/cotton knitted fabric coated with small rectangles of chloroprene rubber		Nylon/cotton knitted fabric coated with a layer chloroprene rubber	
Glove 3	Wt: 53.89 g Wp: 1611 g/m2 Wd: 309 g/m2 HL: 17.5 cm HC: 25 cm Tp: 7.65 mm Td: 0.97 mm	Chloroprene rubber applied between two layers of artificial leather laminated knitted fabric		Polyester knitted mesh fabric	
Glove 4	Wt: 111.26 g Wp: 1644 g/m2 Wd: 868 g/m2 HL:19 cm HC: 27.5 cm Tp: 11.96 mm Td: 2.37 mm	Cow leather outer layer and knitted fabric inner layer with chloroprene rubber and polyurethane foam laminated in between		Cow leather outer layer and knitted fabric inner layer	

The thermal conductivity was measured by using KES-F7 Thermo Labo II (Kato Tech Co., Ltd., Japan). The sample was placed between two heated plates. The bottom heated plate had a constant temperature of 20 ℃ while the top heated plate had a constant temperature of 30 ℃ and both had dimensions of 5×5 cm^2. The average

Table 1 (continued)

Glove	Dimension	Palm		Dorsal	
Glove 5	Wt: 63.14 g Wp: 669 g/m2 Wd: 642 g/m2 HL:19.5 cm HC: 26 cm Tp: 7.48 mm Td: 4.36 mm	Spacer fabric		Spacer fabric	

Wt denotes total glove weight, *Wp* is the weight of palm materials, *Wd* is the weight of dorsal materials, *HL* is hand length, *HC* is hand circumference, *Tp* is thickness of palm material and *Td* is thickness of dorsal material

power of the heater for the top heated plate for 60 s was used to calculate the thermal conductivity of the fabric as follows:

$$k = \frac{W \cdot D}{A \cdot \Delta T} \tag{2}$$

where k is the thermal conductivity (W/cm ℃), W is the heat flow of the top heated plate, D is the thickness of the sample, A is the area of the top heated plate and ΔT is the temperature difference of the two heated plates. The fabric samples were used as the surface of the inner side of the glove facing the bottom heated plate.

The water vapour permeability of the samples was tested in accordance with JIS L1099:2012, Testing methods for water vapour permeability of textiles. The specimens were cut into a circular shape with a diameter of 7 cm. Then, each specimen was fixed and sealed onto the opening of a cup (Yasuda Seiki Seisakusho, Ltd., Japan) with 6 cm in diameter and filled with 33 g of calcium chloride which acted as the desiccant. The test assembly was placed into a climate chamber with temperature and RH maintained at 40 ± 2 °C and 90 ± 5% respectively. The weight of the assembly after 1 and 2 h was measured and the water vapour permeability was calculated as:

$$P = \frac{m_2 - m_1}{S} \tag{3}$$

where P is the water vapour permeability (g/m^2 h), m_1 is the mass of the test assembly after 1 h (g), m_2 is the mass of the test assembly after 2 h (g) and S is the permeated area (m^2).

Evaluation of gloves: wear trial

Subjects

Sixteen male subjects were recruited but only fourteen subjects who were on average 25 ± 3 years old, and had a height of 174 ± 7 cm and weight of 71 ± 11 kg completed the wear trial experiment. Two subjects withdrew from the study. All of the participants were right-handed, had no history of upper limb injury and no wounds on the hand and upper limbs. Their average hand length and hand circumferences were 18.5 ± 0.7 cm and 20.7 ± 0.7 cm respectively, so the medium (M) size glove sample can fit them. A brief overview of the study was given to each participant who signed a written consent form prior to the start of the experiment. The experiment was approved by the Human Subjects Ethics Committee of the first author's university and conducted in accordance with the Declaration of Helsinki (IRB no.: 2020–05).

Experiment protocols

The activities of the wear trial were the same as some of the daily tasks expected of a construction worker. The wear trial procedures are presented in Fig. 1. During the wear trial, the subjects performed (1) sitting for 10 min, (2) transporting a woodblock (dimensions: 45 × 45 × 1000 mm, weight 3.83 kg) 20 times for 5 m, (3) inserting as many as possible screws (length: 40 mm, size: M5) into the holes of a board in 30 s, and (4) screwing 10 screws (length: 40 mm, size: M5) into a woodblock with an impact driver (Makita TD111DSHX, Japan). Each participant had to carry out the experiment 6 times; 5 times with the five types of gloves plus once in the bare hand condition. There was a 1-min break in between the activities of the wear trial and a 10-min rest and homeostasis period after the completion of the wear trial for each hand condition. Before the wear trial experiment commenced, training was given to the participants to learn and become accustomed to the activities. The participants were asked to move the woodblock and insert the screws at their own pace and maintain the same pace under different hand conditions. The environmental conditions were maintained at a temperature of 25 ± 1 ℃ and RH of 50 ± 5%.

Measurements

The glove microclimate is defined as the climate in the area between the glove-skin interface. The temperature and humidity changes of the microclimate can be affected by the glove materials and the hand during different activities. A sensor (Thermochron HC, OnSolution, Australia) was placed on the dorsal of the right hand to continuously measure the skin temperature and RH inside the glove throughout the wear trial. The temperature and humidity sensor was placed on the dorsal of the hand

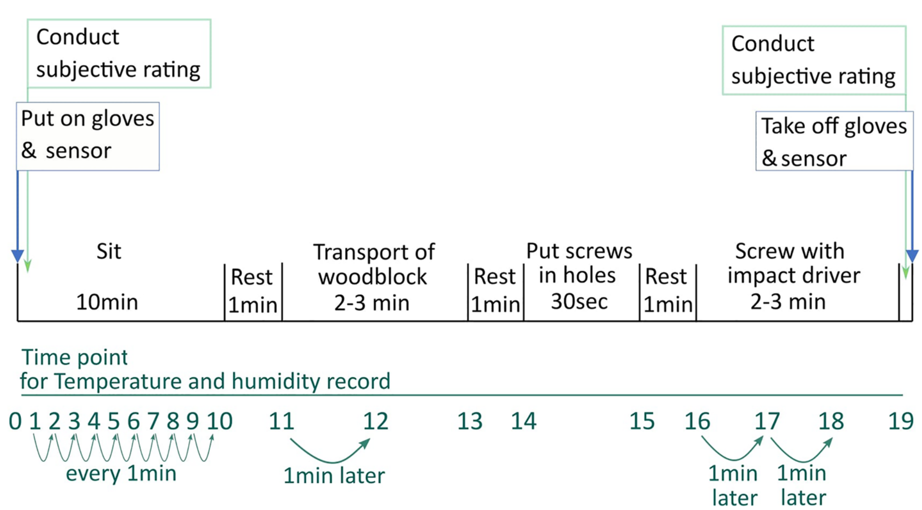

Fig. 1 Experimental procedure of wear trial

instead of the palm to avoid the influence of the sensor during the wear trial activities. A surgical tape was used to attach the sensor to the hand dorsal of the subject. The sensing part of the sensor was facing the skin surface. The skin temperature and RH in a bare hand condition were also measured for comparison. 19 time points, including at every 1 min interval during sitting, the start and end of each activity, the first minute of the woodblock transport task, and the first and the second minutes of the inserting the screw task, were extracted for comparison. Three subjective 9-point rating scales were used for the subjects to assess the wear comfort, thermal sensation, and humidity sensation of each glove immediately after donning the glove and after all of the activities were completed (Fig. 2).

Statistical analysis

Statistical analyses were carried out by using statistical software (SPSS Statistic 21, IBM Corp., USA). Repeated-measures analysis of variance (ANOVA) was used to assess the effect of the hand condition on the skin temperature and RH measured at different time points during the wear trials. Both analyses that took the factor of the six hand conditions including bare hand and the factor of five gloved conditions as the independent variable were conducted. The effect of the five glove samples on the subjective rating of glove wear comfort, thermal sensation, and humidity sensation was also analysed by using repeated-measures ANOVA. Sidak pairwise comparisons were also used to further understand the differences between the glove samples. The alpha level was set at 0.05 for statistical significance.

Results and Discussion

Material properties of gloves

The test results of the fabric properties of both the palm and dorsal sides of the glove samples are presented in Fig. 3. The thermal conductivity of the fabrics of the dorsal

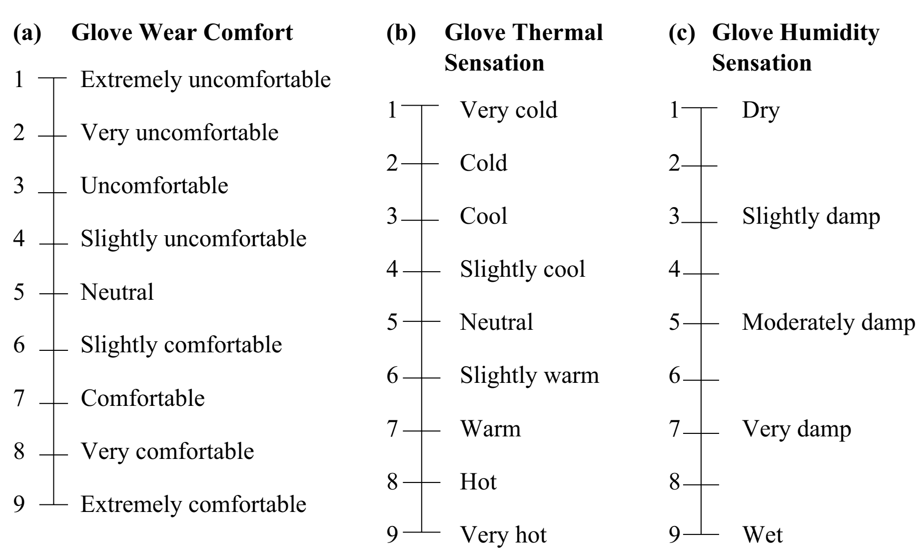

Fig. 2 Subjective rating scales for glove wear comfort (**a**), glove thermal sensation (**b**), and glove humidity sensation (**c**)

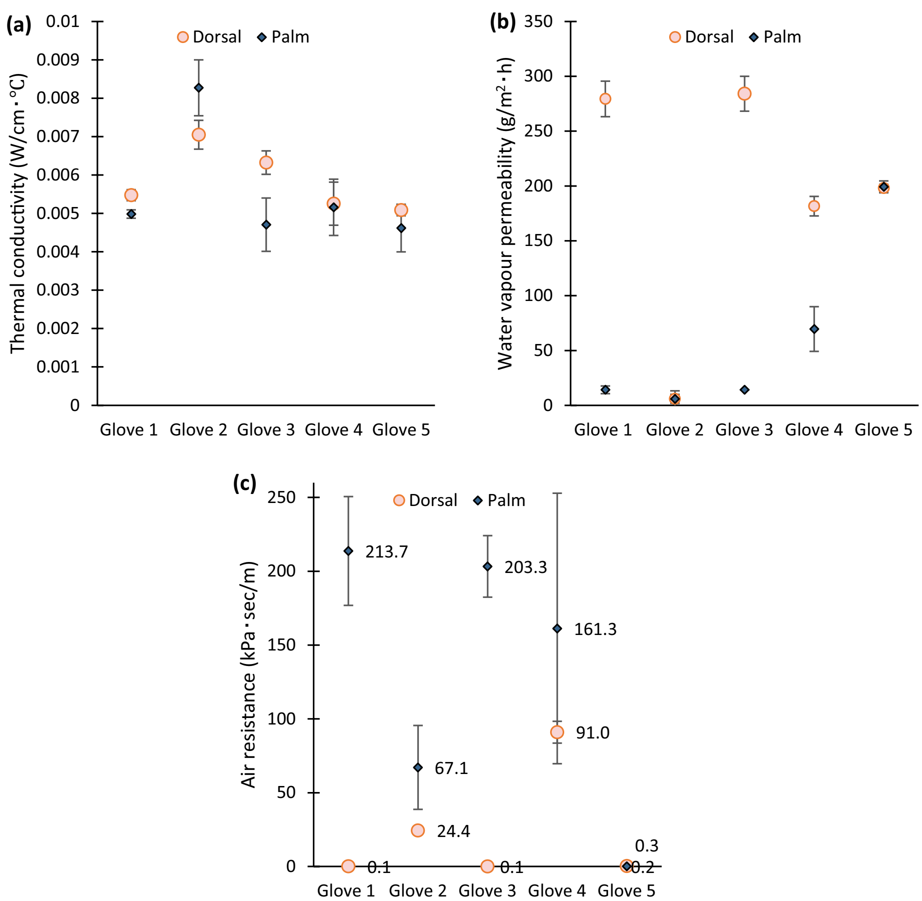

Fig. 3 Thermal conductivity (**a**), water vapour permeability (**b**), and air resistance (**c**) of the materials used for the palm and dorsal of the glove samples. Error bar represents ± standard deviation

and palm of Gloves 1, 4, and 5 and the fabric of the palm of Glove 3 is similar at 0.005 W/cm ℃ on average. The fabrics of Glove 2 and the dorsal of Glove 3 show a relatively higher thermal conductivity. The dorsal fabrics of Gloves 1 and 3 have high water vapour permeability of 279 ± 16 g/m^2 hr and 284 ± 16 g/m^2 hr respectively, followed by the dorsal and palm fabrics of Glove 5 and then the dorsal fabric of Glove 4. On the other hand, the palm fabrics of Gloves 1 and 3 show relatively low water vapour permeability. Amongst the five samples, the dorsal and palm fabrics of Glove 2 have the lowest water vapour permeability. The air resistance is very low for the dorsal fabrics of Gloves 1 and 3 and both dorsal and palm fabrics of Glove 5. The palm fabrics of Gloves 1–4 have much higher air resistance than their dorsal fabrics.

With a relatively higher thermal conductivity, the materials used for Glove 2 and dorsal of Glove 3 allow heat to be easily transferred by conduction. Glove 3 using a dorsal fabric with better thermal conductivity can allow heat to disperse by conduction. However, the vibrating hand tools may emit heat when used and could be hotter than the hand palm. A palm fabric with high thermal conductivity can bring the heat from the tools to the hands. Moreover, the materials used for Glove 2 have the lowest water vapour permeability and relatively high air resistance of 67.1 ± 28.4 kPa sec/m on the palm side. This shows that Glove 2 cannot transmit air and moisture well. The entire Glove 2 is coated with a layer of chloroprene rubber, thus making the glove impermeable to water vapour and air. The heat generated by the hand cannot be easily released to the environment through convection and evaporation.

The material of the palm of Gloves 1–4 is chloroprene rubber to isolate vibration. The palm sides of Gloves 1–4 have lower air and water vapour permeabilities than that of Glove 5. The materials of the palm of Glove 4 have a higher water vapour permeability than that of Gloves 1–3. This is because, apart from chloroprene rubber, some of the palm components of Glove 4 are made of polyurethane foam which allows moisture to pass through. The composition of the materials for the palm of Glove 4 also leads to a large variation in air resistance. The part made of polyurethane foam shows better air permeability than that mainly consisting of chloroprene rubber. On the other hand, the spacer fabric used for the palm of Glove 5 to isolate vibration shows the highest water vapour transmissibility and the lowest air resistance. This shows that spacer fabric can provide much higher breathability than the chloroprene rubber and fabric used for the palm side of the anti-vibration gloves.

Except for Glove 2, fabrics with good water vapour permeability are used on the dorsal side of the glove samples. The fabrics used for the dorsal of Gloves 1 and 3 are not only the thinnest and lightest but also have the best air and water vapour permeabilities. The materials used for the dorsal of Glove 4 have good water vapour permeability but low air permeability due to the use of cow leather and knitted fabric. The spacer fabric used on the dorsal and palm of Glove 5 shows similar air and water vapour permeabilities.

Skin temperature and RH under glove

The skin temperature and RH during the wear trial for the dorsal of the hand are shown in Fig. 4a and b. It is observed that the skin temperature and RH rapidly increase during sitting which may be due to the adaptation of the sensor to the skin condition. The temperature and RH of the skin become stable toward the end of the sitting. By comparing the skin temperature at Time point 10, it is observed that the gloves can significantly increase the skin temperature even when the hands are static, while the effect on RH is not clear. From the results of the repeated-measures ANOVA, no significant difference can be found in the RH of the skin among the 6 hand conditions or between the 5 gloved conditions ($p > 0.05$). The RH of the skin shows a trend of increase during the activities that involved the use of the hands. However, the effect of different types of gloves on the RH of the skin is not significant. This could be because the sensor is placed on the dorsal instead of the palm. The palm is covered by thick materials and has the largest sweat gland density (Kobielak et al., 2015). Therefore, most of the sweating takes place in the palm, while the effect of the glove on the RH of the skin of the dorsal is not significant.

On the other hand, there is a significant effect of the type of glove on the skin temperature. Although no significant difference in the skin temperature is found among the 6 hand conditions at the start (T_0) of the wear trial ($p > 0.05$), the bare hand condition shows a significantly lower skin temperature than the gloved condition during the wear trial. All five glove samples have a larger increment in skin temperature than the bare hand condition. From the results of the repeated-measures ANOVA which compared the 5 gloved conditions, significant differences can be found in the skin temperature at different time points. The pairwise comparison shows that from the ninth minute

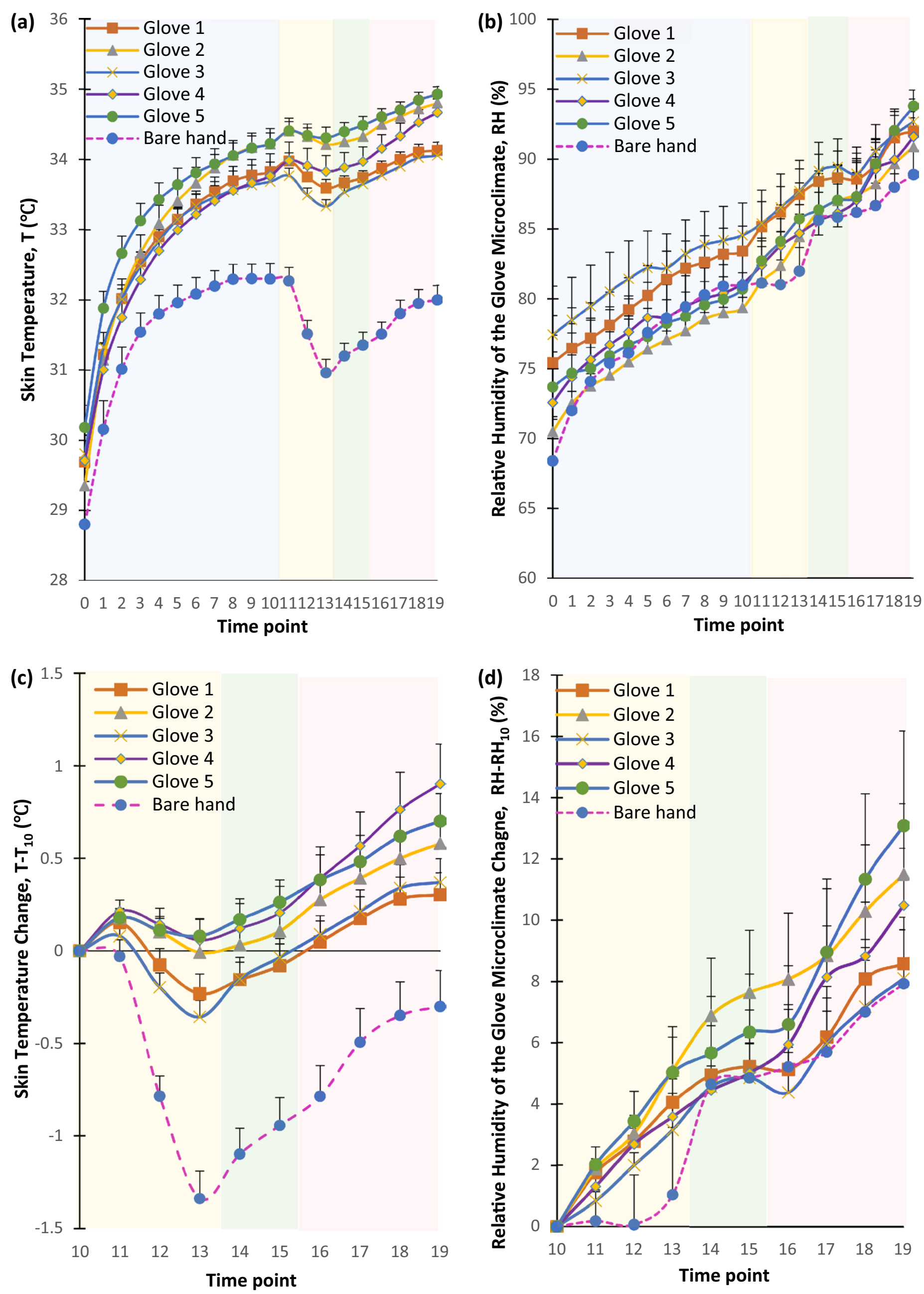

Fig. 4 Skin temperature (**a**), relative humidity of the glove microclimate (**b**), skin temperature change (**c**), and relative humidity of the glove microclimate change (**d**) on the right hand dorsal with donned gloves and bare hand during wear trial. Error bar represents the standard error

of sitting to the end of the wear trial, significant differences ($p < 0.05$) can be observed between Gloves 2 and 3, and Gloves 3 and 5. Wearing Gloves 2 and 5 results in significantly higher skin temperatures than wearing Glove 3. The differences in the mean skin temperature between Gloves 2 and 3, and Gloves 3 and 5 from Time point 9 to the end of the wear trial are 0.54–0.88 ℃ and 0.53–0.98 ℃, respectively. The largest mean skin temperature differences are found at Time Point 13 for both pairs. Starting from the Time point 12 (1 min after the woodblock transport activity) to the end of the wear trial, significant differences ($p < 0.05$) are also found between Gloves 1 and 2, and Gloves 1 and 5. The skin temperature with the use of Glove 1 is also significantly lower than with Gloves 2 and 5. The differences in the mean skin temperature between Gloves 1 and 2, and Gloves 1 and 5 from Time point 12 to the end of the wear trial are 0.58–0.67 ℃ and 0.59–0.8 ℃, respectively. The skin temperature when using Gloves 2 and 5 is significantly higher than Gloves 1 and 3 when performing the tasks. In order to investigate the effect of gloves in bringing further changes to the skin conditions during different hand activities, the changes are calculated by comparing the skin temperature and RH with Time point 10 (Fig. 4c and d). Gloves 1 and 3 show a relatively larger rate of temperature decrease during the transport of the woodblocks. The subjects have to walk for a short distance and the hands swing to pick up and put down the woodblock, which allows some of the heat to dissipate through convention. The thin mesh fabric of the dorsal of Gloves 1 and 3 with good air and water vapour permeabilities can facilitate a significant difference in heat dissipation. The fabric of the dorsal of Glove 3 is thinner and has a higher thermal conductivity than Glove 1. Therefore, Glove 3 shows a lower skin temperature on average than Glove 1. This shows that using a thin and permeable fabric for the dorsal of the hand can reduce the heat accumulated inside the gloves during work tasks.

The fabric and materials used for Glove 2 are heavy and have poor air and water vapour permeabilities. Therefore, Glove 2 has the highest increment in skin temperature in the wear trial. However, Glove 5 is made of spacer fabrics which have good air and vapour permeabilities. It is unexpected that the skin temperature with Glove 5 is significantly higher than Gloves 1 and 3. The fabric of the dorsal of Glove 5 is the thickest amongst the five glove samples. According to Yu and Sukigara (2022), Glove 5 has more impact on hand dexterity and requires higher muscle activity in performing the wear trial activities compared to Gloves 1–4. As more effort is needed to use Glove 5, more heat would be generated by the hands during the activities, thus resulting in a higher skin temperature. Although spacer fabric is a good material for isolating vibration (Chen et al., 2018; Chen et al., 2016; Liu & Hu 2015; Yu et al., 2020) and has good air and water vapour permeabilities, its use as the material of the dorsal of anti-vibration gloves could lead to high skin temperature due to its bulkiness which inhibits hand movement. On the other hand, the palm of Glove 4 is the thickest and shows a high rate of temperature increment during hand activities. Glove 4 has the widest wrist opening which could allow the heat to escape leading to a slightly lower average skin temperature than Gloves 2 and 5. This further shows the importance of using a thin and flexible fabric for the dorsal of the glove and proper glove design to enhance thermal comfort.

Subjective perception of gloves

The results of the subjective assessment at the start and end of the wear trial are shown in Fig. 5. There are significant differences between the three subjective ratings taken at the start and end of the wear trials. The glove wear comfort significantly decreases after the wear trial activities are completed, whereas the glove RH and thermal sensation increase. Significant differences are found between the five types of gloves in glove wear comfort and glove humidity sensation. However, the glove samples have no significant

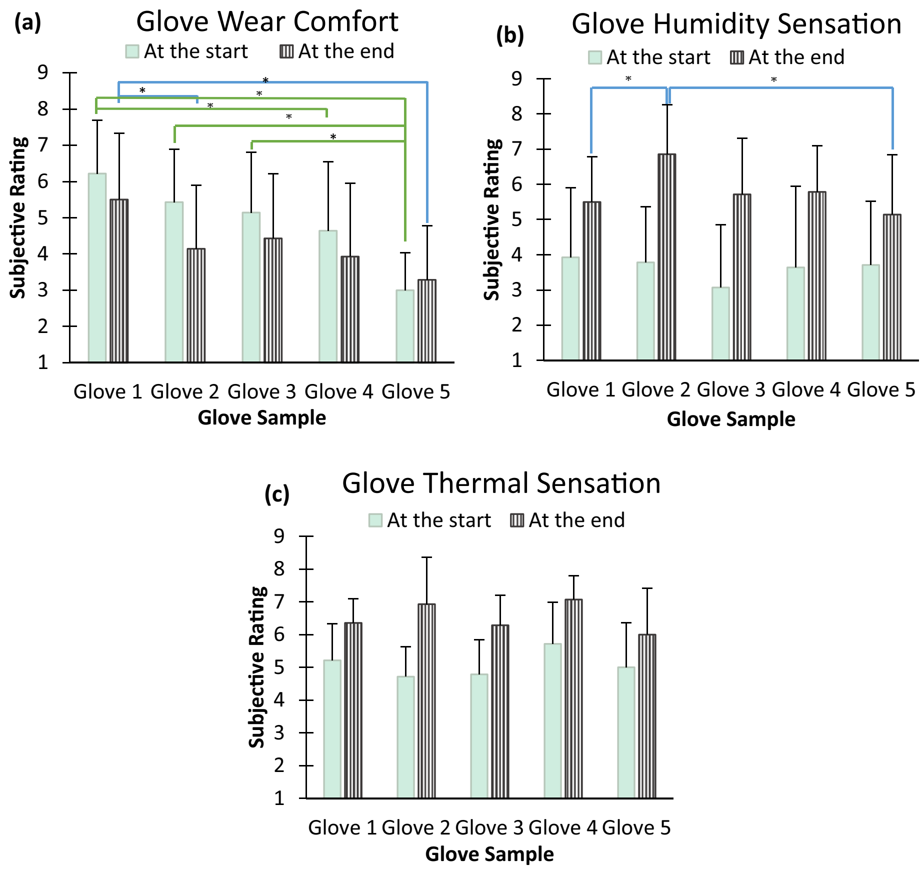

Fig. 5 Subjective rating results for the five gloves: glove wear comfort (**a**), glove humidity sensation (**b**), and glove thermal sensation (**c**). Error bar represents the standard deviation, and * indicates a significant difference ($p < 0.05$)

influence on the thermal sensation. For the glove comfort perception, Glove 5 has a significantly lower rating than Gloves 1–3 at the start of the wear trial and lower than Glove 1 only at the end of the wear trial. The average rating of Glove 5 is even slightly increased after the wear trial. Glove 5 could be bulkier than the other gloves to have the lowest wear comfort rating initially. However, after conducting different activities with hands, the wear comfort of all the gloves changes and the gap between Glove 5 and the other gloves becomes smaller. This shows that using spacer fabric instead of chloroprene rubber could reduce the decline in glove wear comfort caused by working. Although the spacer fabrics used in Glove 5 are lightweight and have good permeability to air and water vapour, the glove wear comfort is the lowest. Other than the material properties, factors such as fabric thickness and glove design can also influence glove comfort.

On the other hand, Glove 2 is entirely coated with chloroprene rubber and thus has poor air and water vapour permeabilities. Although the perception rating of Glove 2 is similar to Gloves 1, 3, and 4 at the start of the wear trial, Glove 2 shows a significantly higher humidity sensation than Gloves 1 and 5 and lower glove wear comfort than Glove 1 at the end of the wear trial. Glove 2 also shows the largest average decrement in glove wear comfort and the largest average increment in glove humidity and thermal sensations after the wear trial. This shows that using a large proportion of mostly unbreathable materials like chloroprene rubber can negatively affect glove wear comfort after a short duration of hand activity.

Anti-vibration gloves require a thick material for the palms to isolate vibrations. Therefore, the dorsal side plays an important role in dissipating the heat inside the glove. Glove 1 has the highest glove wear comfort. The fabrics used to construct Glove 1 are light and thin compared to the other glove samples. The highly air and water vapour permeable fabric of the dorsal of Glove 1 can also help to improve the glove wear comfort. This further shows that light and thin gloves offer good breathability on the dorsal side which can improve wear comfort.

Conclusions

Anti-vibration gloves make use of vibration isolation materials to protect hands during industrial work. Unlike previous studies focusing on the vibration reduction functions, this study investigates the thermal properties of the gloves and the effect on wearing comfort. The thermal properties of the palm and dorsal of five types of anti-vibration gloves were investigated by objectively evaluating the fabric and through a wear trial. The palm of the anti-vibration glove has to provide vibration isolation function. The use of chloroprene rubber or coating of chloroprene rubber significantly reduces the air and water vapour permeabilities while using polyurethane foam to replace some of the chloroprene rubber can help to increase the water vapour permeability. The glove made of spacer fabric shows the highest air and water vapour permeabilities, thus resulting in a breathable glove. The fabric used for the dorsal of the glove plays an important role in dissipating the heat from the inside of the glove. The glove with a thick spacer fabric or an impermeable chloroprene coated fabric for the dorsal demonstrates a significantly higher skin temperature than that made of thin mesh fabric during activity. No significant difference in the thermal sensation between the gloves can be observed. The gloves made with chloroprene rubber show a decrease in glove wear comfort after the subjects carried out the wear trial activities. The glove entirely coated with chloroprene rubber resulting in the highest glove humidity sensation at the end of the wear trial. The glove made of spacer fabric shows the lowest wear comfort. The glove wear comfort slightly increases after conducting the different activities. Apart from using highly permeable materials, the fabric thickness and design should also be considered in the development of anti-vibration gloves to provide better wear and thermal comfort.

This study has some limitations. The wear trial was carried out at an environment condition of 25 ± 1 ℃ and RH of $50 \pm 5\%$ which is thermally comfortable. The results cannot reflect the effect of anti-vibration gloves under high heat burden conditions such as outdoor summer conditions. Further studies under higher temperature and RH is recommended to provide a better understanding of thermal comfort of the glove under different conditions. The measurement of the skin temperature and RH under glove was only taken at one point on the dorsal side. However, the vibration isolation materials are located on the palm and the thermal condition of the palm could be valuable in evaluating the thermal comfort of anti-vibration gloves. It is suggested to carry out further study on anti-vibration gloves by using thermal hand manikin or building a finite element simulation model for heat transfer.

Authors' contributions
AY contributes in the conceptualisation, methodology, formal analysis, data curation, paper writing, funding acquisition. SS contributes in reviewing and giving advices for the projects. All authors read and approved the final manuscript.

Authors' information
Dr. AY is an assistance professor of Faculty of Fiber Science and Engineering, Kyoto Institute of Technology. Her research interests include knitted fabric design, textiles product development, anthropometry measurements and sensory comfort properties of clothing. Prof SS is a professor of Faculty of Fiber Science and Engineering, Kyoto Institute of Technology. Her research interests includes fabrics and materials sensory evaluation.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics and consent
This research was conducted under the approval and supervision of the Kyoto Institute of Technology Institutional Review Board (IRB Approval No. 2020-05) regarding ethical issues including consent to participate.

Competing interests
The authors declare that they have no competing interests.

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References
Bagherzadeh, R., Gorji, M., Latifi, M., Payvandy, P., & Kong, L. X. (2012). Evolution of moisture management behavior of high-wicking 3D warp knitted spacer fabrics. *Fibers and Polymers, 13*(4), 529–534. https://doi.org/10.1007/s12221-012-0529-6
Brammer, A. J., Taylor, W., & Lundborg, G. (1987). Sensorineural stages of the hand-arm vibration syndrome. *Scandinavian Journal of Work, Environment & Health*. *13*(4), 279–283. https://doi.org/10.5271/sjweh.2050
Cabeças, J. M., & Milho, R. J. (2011). The efforts in the forearm during the use of anti-vibration gloves in simulated work tasks. *International Journal of Industrial Ergonomics, 41*(3), 289–297. https://doi.org/10.1016/j.ergon.2011.01.013
Chen, C., Chen, J., Sun, F., Yang, H., Lv, Z., Zhou, Q., Zhaoqun, D., & Weidong, Y. (2018). Study of the vibration transmission property of warp-knitted spacer fabrics under forced sinusoidal excitation vibration. *Textile Research Journal, 88*(8), 922–931. https://doi.org/10.1177/0040517517690630
Chen, F., Liu, Y., & Hu, H. (2016). An experimental study on vibration isolation performance of weft-knitted spacer fabrics. *Textile Research Journal, 86*(20), 2225–2235. https://doi.org/10.1177/0040517515622149
Chen, Q., Shou, D., Zheng, R., Tang, K. P. M., Fu, B., Zhang, X., & Ma, P. (2021). Moisture and thermal transport properties of different polyester warp-knitted spacer fabric for protective application. *Autex Research Journal, 21*(2), 182–191. https://doi.org/10.2478/aut-2020-0013
Chetter, I. C., Kent, P. J., & Kester, R. C. (1997). The hand arm vibration syndrome: a review. *Cardiovascular Surgery, 6*(1), 1–9. https://doi.org/10.1016/S0967-2109(97)00090-2
Chowdhry, R., & Sethi, V. (2017). Hand arm vibration syndrome in dentistry: a review. *Current Medicine Research and Practice, 7*(6), 235–239. https://doi.org/10.1016/j.cmrp.2017.11.001
Dong, R. G., McDowell, T. W., Welcome, D. E., Warren, C., Wu, J. Z., & Rakheja, S. (2009). Analysis of anti-vibration gloves mechanism and evaluation methods. *Journal of Sound and Vibration, 321*(1–2), 435–453.
Du, Z., Wu, Y., Li, M., & He, L. (2015). Analysis of structure of warp-knitted spacer fabric on pressure indices. *Fibers and Polymers, 16*(11), 2491–2496. https://doi.org/10.1007/s12221-015-5363-1
Gemne, G. (1997). Diagnostics of hand-arm system disorders in workers who use vibrating tools. *Occupational and Environmental Medicine, 54*(2), 90–95. https://doi.org/10.1136/oem.54.2.90
Gerhardsson, L., & Hagberg, M. (2014). Work ability in vibration-exposed workers. *Occupational Medicine, 64*(8), 629–634. https://doi.org/10.1093/occmed/kqu121
Hewitt, S., Dong, R., McDowell, T., & Welcome, D. (2016). The efficacy of anti-vibration gloves. *Acoustics Australia, 44*(1), 121–127. https://doi.org/10.1007/s40857-015-0040-5
Hewitt, S., Dong, R. G., Welcome, D. E., & McDowell, T. W. (2015). Anti-vibration gloves? *Annals of Occupational Hygiene, 59*(2), 127–141.
Kobielak, K., Kandyba, E., & Leung, Y. (2015). Chapter 22 - Skin and skin appendage regeneration. In A. Atala & J. G. Allickson (Eds.), *Translational Regenerative Medicine* (pp. 269–292). Academic Press.
Liu, Y., & Hu, H. (2011). Compression property and air permeability of weft-knitted spacer fabrics. *Journal of the Textile Institute, 102*(4), 366–372.
Liu, Y., & Hu, H. (2015). Vibration isolation behaviour of 3D polymeric knitted spacer fabrics under harmonic vibration testing conditions. *Polymer Testing, 47*, 120–129. https://doi.org/10.1016/j.polymertesting.2015.09.003
Mas'aud, N. H., & Abdullah, B. (2015). Evaluation of different type of glove using vibrating hand tool. *Jurnal Teknologi*. https://doi.org/10.11113/jt.v76.5667

MdRezali, K. A., & Griffin, M. J. (2016). Transmission of vibration through gloves: effects of material thickness. *Ergonomics, 59*(8), 1026–1037.
MdRezali, K. A., & Griffin, M. J. (2017). Transmission of vibration through gloves: effects of contact area. *Ergonomics, 60*(1), 69–81.
PalaniRajan, T., Kandhavadivu, P., & Periyasamy, A. P. (2021). Influence of porosity and yarn linear density on the thermal behaviour of polyester warp knitted spacer fabrics. *Fibers and Polymers, 22*(11), 3212–3221. https://doi.org/10.1007/s12221-021-0707-5
Taghvaie, M., Payvandy, P., & Jalili, M. M. (2020). Introduction and optimization of a novel nonlinear model for the free vibration of Warp-knitted spacer fabrics. *Fibers and Polymers, 21*(8), 1849–1856. https://doi.org/10.1007/s12221-020-9780-4
Yu, A., & Sukigara, S. (2022). Evaluation of the design and materials of anti-vibration gloves: impact on hand dexterity and forearm muscle activity. *Applied Ergonomics*. Article e103572. https://doi.org/10.1016/j.apergo.2021.103572.
Yu, A., Sukigara, S., & Masuda, A. (2020). Investigation of vibration isolation behaviour of spacer Fabrics with elastic Inlay. *Journal of Textile Engineering, 66*(5), 65–69. https://doi.org/10.4188/jte.66.65

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