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Thermal effects of rayon and polyester hijabs in warm-humid and hot-dry environments

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Abstract

Hijabs are predominantly worn in hot environments, but very rare studies on the thermo-physiological effects of wearing hijabs are found. We investigated the effects of wearing rayon and polyester hijabs on wearers' physiological and subjective responses in warm-humid and hot-dry environments. Eight females (25.0 ± 2.3 y in age, 157.7 ± 4.1 cm in height, and 50.8 ± 7.5 kg in weight) participated in three conditions (No hijab, rayon hijab, and polyester hijab condition) during exercise in two thermal environments: a warm-humid (30 °C and 70%RH) and a hot-dry environment (36 °C and 30%RH), which generated an identical wet-bulb globe temperature at 27 °C. The results showed that no differences in rectal temperature were found among the three clothing conditions or the two environments, whereas auditory canal temperature was higher in the hot-dry than in the warm-humid environment ($P < 0.05$) with no differences between the polyester and rayon hijab conditions. Mean skin temperature and neck temperature were higher for the polyester condition than for the rayon condition in the warm-humid environment ($P < 0.05$). Sweat rate was greater for the polyester hijab condition than for the no hijab condition in the warm-humid environment ($P = 0.049$). Heart rate was greater for the polyester hijab condition than for the other two conditions in the warm-humid environment ($P < 0.05$). Subjects felt more thermally uncomfortable when wearing the polyester hijab than the rayon hijab in the warm-humid environment. Greater thermal burden of the polyester hijab when compared to the rayon hijab was marked in the warm-humid environment, not in the hot-dry environment.

Keywords: Total sweat rate, Wet-bulb globe temperature (WBGT), Tropical females, Hijab materials, Heat strain

Introduction

Hijab (headscarf and cloak) is a Muslim dress whose norm and utilization have been set up in Islamic law, which covers the head, neck and chest, and conceals the female hair, leaving the face uncovered (Al-Ajmi et al., 2008). Designs of hijabs that are as of now accessible in the market end up looking more in vogue with different shapes, shadings, and examples achieving an incredible interest and becoming a pattern among Muslim in Indonesia (Gatot et al., 2016). Indonesia has the largest Muslim population in the world, with 84% of the total population (nationsonline.com, 2021). The influx of fashion items on the hijab led to the development of the meaning of the hijab itself. Indonesia,

Malaysia, Afghanistan, Arabia, Iran, and several Muslim countries have their own responses to the meaning of hijabs. As a result of cultural differences between Muslim countries, some women wear the hijab as an identity for nationality, race, or cultural differences, especially in multicultural countries (Gatot et al., 2016).

Fabrics for hijabs can be made of 100% cotton, rayon, or polyester blends with knit or woven materials, but consideration factors for Muslim women are drape shape, comfort functions (Alsalamah, 2019), colour (Alsalamah, 2019; Hassim et al., 2014), or hygiene (Mutahhari, 2000). According to occasions, other factors could be considered more important when choosing hijab materials (Baharudin et al., 2021). Nowadays, hijabs are also being considered by global fashion brands such as Nike. Nike designed a hijab that specialized in sports activities with stretches to adapt to the wearer's head (Scarono in Baharudin et al., 2021). Hijab materials should be chosen carefully, especially for sports activities under heat stress, to minimize the unpleasant experience of wearing hijabs, such as sweating on the neck, flapping around when moving, or unsightly perspiration stains (Baharudin et al., 2021).

Cotton is natural fibers from cellulosic fibers. Rayon has the same chemical composition and molecular structure as the natural cellulosic found in cotton (Kadolph, 2010). Both have higher hygroscopicity than typical polyester (Elsasser, 2010), which is advantageous for absorbing sweat in summer. However, sweat-absorbent and quick-drying fabrics can be achieved by using 100% polyester and structuring the polyester fabric with long and thin capillaries. Moisture management characteristics are influenced by water absorption, vertical and horizontal wicking, air permeability, water vapor transmission, thermal resistance, or drying rate (Bonaldi, 2018). Hijab materials with effective moisture management properties can contribute to wearer comfort, particularly due to the higher metabolic activity associated with physical exertion.

Even though the huge population of Muslim women exist worldwide, there are very few studies reporting the thermoregulatory performance according to the material of hijabs in hot environments. Hijab materials are selected with hijab users' preferences so that they feel comfortable in their own climates. Muslim-majority countries are in hot-dry or warm-humid climates. Indonesia and Malaysia are characterized by a warm-humid environment and other countries in the Middle East have hot-dry climates. Ansari and Solomon (2015) discussed the hijab headache of Muslim women from a medical viewpoint, which is explained by the relation of the hijab to extracranial tissues and friction against the hair. Surprisingly, however, there is very few studies evaluating the physiological effects of the material of hijabs in hot environments. Recently, Yusof et al. (2021) did a survey on subjective perceptions of wearing casual hijabs experienced by 100 Muslim women in Malaysia while doing sports activities. They found that skin wetness, heat sensation and unpleasant odour were significant factors which triggered discomfort during sports activities. From the material aspect, they interpreted that the excessive skin wetness could occur due to material characteristics that is not moisture-wicking but highly absorbent such as cotton.

In particular, hijabs cover the head where the thermoregulatory center is located. Bogerd et al. (2015) reviewed that head gear is mainly problematic because wearing headgear increases head insulation under heat stress. Heat transfer through headgear is relevant to radiation, convection, and evaporation. While exercising in hot environments,

evaporative heat dissipation from sweating will be more significant pathway. In this regard, studies on the distribution of sweat rate on the head area (Jung et al., 2018) receive more attention. Nadel and colleagues in Hensel (1981) found that the face had the highest sensitivity of sweat to warming. When cycle-exercising under heat stress, heat loss from the head was estimated at 200–250 W (Rasch et al., 1991), which is higher portion of the entire metabolic heat when considering the head's proportion of the body surface area (e.g., 7% body surface area). According to these studies, it can be expected that wearing a hijab in hot environments can increase heat strain by interfering with convective and evaporative heat loss from the head, but this has not been scientifically verified. It might be advantageous for body temperature regulation by blocking radiant heat by using a hat or a parasol under the sun's radiation (Gies et al., 2006), but there are very rare studies on the thermo-physiological effects of wearing casual hijabs with different materials in hot environments, without strong radiation from the sun.

Therefore, the present study aimed to explore the effects of hijab materials on thermo-physiological responses and subjective perception of wearers during rest and exercise in hot-dry (HD) and warm-humid (WH) environments. We hypothesized that (1) heat strain would be greater for the synthetic (polyester) hijab condition than for the cellulose (rayon) hijab condition, (2) the heat strain of wearers would be greater for the hot-dry condition (36C30%RH) than for the warm-humid condition (30C70%RH) even though the wet-bulb globe temperature (WBGT) of the two environments is identical, and (3) wearing hijabs would provide greater thermal strain when compared to a condition with no hijab in hot environments.

Methods

Survey to determine hijab materials

As the first step, a survey was conducted to determine the representative materials of contemporary hijabs for the human wear trials in a climate chamber. We constructed a questionnaire and distributed the survey link to Muslim women via Google forms. The survey was written in Indonesian and then translated into English (IRB no. 2202/002-016). "The sentences and linguistic structures were examined by a native speaker of both languages. The following four categories were used to organize the items: (1) demographic data (age, country, occupation, and education), and (2) hijab materials (most common material, favourite material, and most uncomfortable material), and (3) habit of wearing hijabs (type hijab to wear, using inner hijab or no, type inner hijab, what type of hijabs that wears while doing exercise, etc.). All respondents gave their informed agreement to participate in the survey. A total of 302 women replied to the survey [age: 10 s (5%), 20 s (68.2%), 30 s (22.2%), 40 s (3.3%), and 50 s (1.3%); Indonesian (89.4%), Malaysian (8.3%), and other nations; college students (39.9%), private employees (23.3%), government employees (10.6%), housewives (14%), students (5.6%), and others (6.6%)]. The majority of survey respondents (94.5%) said that they wear hijabs whenever they go out. They owned hijabs made of cellulose, such as cotton or rayon (61.8%), polyester (14.6%), nylon (6.6%), silk (3.5%), and other materials (5.5%). The majority of hijab wearers utilized an inner hijab to keep their hair inside their hijab (ninja model 70.0%, bandana inner hijab 67.2%). Based on the survey results, we chose two materials for the hijab wear trials in a climate chamber: rayon 100% and polyester 100%.

Subjects

Eight young female students participated in this study (25.0 ± 2.3 y in age, 157.7 ± 4.1 cm in height, 50.8 ± 7.5 kg in body weight, and 1.49 ± 0.11 m^2 in body surface area). All of the participants were Asians from tropical countries (Indonesia and Laos) who had spent 1 ~ 3 years in Seoul (South Korea). They were free of any cardiovascular or skin diseases. Subjects were told not to drink alcohol or take any medication prior to the 48 h of the participation, and they were told about the study's goal and methods in advance. The subject number of the present study was determined using the G-power sample size analysis (alpha error 0.05, power 0.95, effect size 0.8, three hijab conditions, and repeated measurements). All subjects gave their written informed consent. This study was approved by Seoul National University's Institutional Review Board (IRB no. 2202/002-016).

Experimental conditions and procedures

Subjects participated in a total of six experimental conditions (two ambient environments × three clothing conditions). A climate chamber was set in a warm-humid (WH) environment (30 °C and 70%RH [30C70% condition]) or a hot-dry (HD) environment (36 °C and 30%RH [36C30% condition]), which had an identical WBGT at 27 °C. Clothing conditions consisted of the following: Control (without wearing a hijab), a rayon hijab (rayon 100%, 75 g in hijab mass, 106.5 × 103.5 cm in size, and white in colour), and a polyester hijab (polyester 100%, 75 g, 109 × 105 cm, and white). The physical properties of the rayon and polyester materials were presented in Table 1. The unit mass and thickness of two materials were almost similar. Except for the hijab, subjects wore all identical clothing (an inner hijab [bandana type], long-sleeve shirts, long pants, bra and panty, socks, and running shoes; 615 g in total clothing mass without the shoes). The thermal insulation of the clothing ensemble was estimated as 0.6 clo based on ISO 9920 (2009). The experimental conditions of the two hijab materials were blinded to subjects.

All of the subjects visited the laboratory in the morning. They took a break upon arrival, drinking 300 mL of water to avoid dehydration, and then they went to the bathroom if needed. To establish total sweat rate, we measured subject's body weight

Table 1 Physical characteristics of hijab materials used in the present study

Item	Rayon	Polyester	Test method
Fiber composition (%)	Rayon 100	Polyester 100	KS K 0210: 2018
Weight (g/m^2)	74.3	74.8	KS K 0514:2017
Thickness (mm)	0.18	0.26	KS K 0642: 2016
Density (threads/cm)	Warp/weft: 58/41	Warp/weft: 25/23	KS K ISO 7211-2: 1984
Air permeability (mm/s)	480	2464	KS K ISO 9237:1995
Water vapor permeability (g/m^2. 24 h))	55,285	42,046	KS K 0594:2021, Potassium Acetate Method
Drying rate (min)	34.5	19.3	KS K ISO 17617: 2014, Method A1
Static water absorption (%)	54.2	18.2	KS K 0642: 2016, 8.26.2
Absorption rate (mm)	Warp/weft: 65/62	Warp/weft: 61/56	KS K 0642: 2016, 8.26.1, Method B (Byreck)
Overall Moisture Management Capacity, OMMC (Level)	0.4544 #1	0.6213 #2	AATCC ™ 195–2011(2017) #Grade

three times before attaching all sensors to their body, using a body scale in a semi-naked state (wearing a lab gown, bra, and panty only) before and after the experiment. After measuring their body weight, sensors were attached to the skin. Then, rectal temperature, auditory canal temperature, heart rate, and microclimate temperature were checked if the values were ranged in thermal neutral ranges (e.g., 37.0 ± 0.4 °C in rectal temperature, 70 ± 10 bpm in heart rate, and 32 ± 1 °C in clothing microclimate temperature). After the subjects entered the climate chamber, we attached sweat capsules to monitor local sweat rates on the back neck in the climate chamber, which was maintained in the hot-dry or warm-humid environment. A trial consisted of 10-min rest on a chair, followed by 20-min walking on a treadmill at a speed of 2 $km \cdot h^{-1}$, and 20-min walking fast at a speed of 4 $km \cdot h^{-1}$, and 20-min jogging at a rate of 6 $km \cdot h^{-1}$, and the last 10-min for recovery on the chair. At the same time, subjects were asked every 10 min about their subjective perceptual responses. All subjects participated in the six conditions at random in order to avoid any possible order effects. All measurements were conducted by female researchers. All trials were conducted from 8:00 am to 10:00 am, or 10:30 am to 12:30 pm to avoid any effects of circadian rhythm.

Measurements

A rectal probe inserted 15 cm and data logger were used to measure rectal temperature (T_{re}) (LT-8A, Gram Corporation, Japan). Auditory canal temperature (T_{ac}) and the skin temperature (T_{sk}) were recorded every 5 s on the forehead, cheek, front neck, back neck, chest, abdomen, forearm, hand, thigh, calf, and foot. Mean skin temperature (*mean* T_{sk}) was calculated using a modified Hardy and Dubois (1938)'s 7-Point formula: $mean\ T_{sk} = 0.07(T_{forehead} + T_{cheek} + T_{neck\ back} + T_{front\ neck})/4 + 0.35(T_{chest} + T_{abdomen})/2 + 0.14T_{forearm} + 0.05T_{hand} + 0.19T_{thigh} + 0.13T_{calf} + 0.07T_{foot}$.

A perspiration meter with a ventilated capsule with a 0.25 cm^2 surface area was used to constantly monitor local sweat rate (LSR) on the back neck every 1 s (SKN-2000 Perspiration Meter; SKINOS, Japan). A portable chest belt and a wrist watch were used to measure heart rate (HR) every 1 s (RC3 GPS, Polar Electro, Finland). The LSR and HR data were sorted every 5 s for data analysis. Total sweat rate (TSR) was calculated using a change in total body mass, which was measured pre- and post-trial (three repetitions for each measurement) on a body scale in the semi-nude state (ID2, Mettler-Toledo, Germany: the resolution of 1 g). Sweat rate absorbed by hijab materials was estimated using the change in the total clothing mass between pre- and post-experiment.

Perceptual responses were obtained every 10 min using the following categorical scales: 9-point thermal sensation (4: very hot, 3: hot, 2: warm, 1: slightly warm, 0: neutral, − 1: slightly cool, − 2: cool, − 3: cold, and − 4: very cold) (ISO 10551, 1995); 7-point sweat sensation (3: very wet, 2: wet, 1: a little wet, 0: neither, − 1: a little dry, − 2: dry, and − 3: very dry); 7-point thermal comfort (3: very uncomfortable, 2: uncomfortable, 1: a little uncomfortable, 0: neither, − 1: a little comfortable, − 2: comfortable, and − 3: very comfortable) (Epstein and Moran, 2006), and 7-point thirst sensation (0: not thirsty, 0.5, 1: a little thirsty, 1.5, 2: thirsty, and 2.5, 3: very thirsty). Thermal sensation, thermal comfort, and sweat sensation were asked on the whole (overall) body and the back neck.

Data analysis

All data were expressed as mean and standard deviation (mean ± SD) for tables; mean and standard error (mean ± SE) for figures. For analytical and graphical purposes, all temperatures, HR, and LSR data were averaged into 1 min. In the continuously measured physiological responses, the first 5-min average (0th–5th min for the rest session) and the last 3-min average (67th–70th for the exercise session; 77th–80th for the recovery session) were selected to represent resting, exercise, and recovery values, respectively. Changes were calculated by subtracting a resting value from an exercise or recovery value. Statistical analysis was performed using SPSS 27.0 with a significance level at $P < 0.05$. Prior to performing further statistical analyses, all data were assessed for normality and sphericity. Repeated measures two-way ANOVA with a Tukey test as a post hoc was conducted. Wilcoxon signed-rank test or Kruskal–Wallis test for non-parametric data with Bonferroni correction was undertaken to compare the two ambient conditions of the three hijab conditions.

Results

Rectal temperature (T_{re}) and auditory canal temperature (T_{ac})

There were no significant differences in T_{re} between the two environments (Fig. 1A, B). The increases of T_{re} (ΔT_{re}) in the hot-dry environments were 1.0 ± 0.2 °C for the rayon hijab and 0.9 ± 0.4 °C for the polyester hijab ($P = 0.521$). The highest T_{re} were, on average, 37.7 ~ 38.0 °C without any difference among the three clothing conditions. T_{ac} were significantly higher for the rayon and polyester conditions than for control, especially in the warm-humid condition ($P < 0.001$), while there were no differences between the two hijab conditions (Fig. 1C, D). In addition, T_{ac} were significantly higher in the hot-dry condition than in the warm-humid condition during exercise and recovery phases ($P < 0.05$). Significant interactions between environments and hijab conditions were found during exercise ($P < 0.05$).

Mean skin temperature ($\overline{T}_{sk}$) and regional skin temperatures (T_{sk})

$\overline{T}_{sk}$ showed no difference among the three clothing conditions in the hot-dry condition, but was higher for the polyester condition than for the rayon condition during exercise at 6 $km \cdot h^{-1}$ and recovery in the warm-humid condition ($P < 0.01$) (Fig. 1E and F). Regarding the effect of environments, *mean* T_{sk} was approximately 0.3 ~ 1.0 °C higher in the hot-dry condition than in the warm-humid condition ($P < 0.05$). Significant interactions between environments and hijab conditions were found at the end of exercise and recovery ($P < 0.05$).

Forehead and cheek temperatures did not show any significant differences among the three hijab conditions (Fig. 2A–D), while front and back neck temperatures were higher for the polyester and rayon conditions than for the control, especially in the warm-humid condition ($P < 0.05$) (Fig. 2E and G). During recovery in the hot-dry condition, neck temperatures were higher for the polyester and rayon conditions than for the control ($P < 0.05$) (Fig. 2F and H). For the both environments, neck temperatures

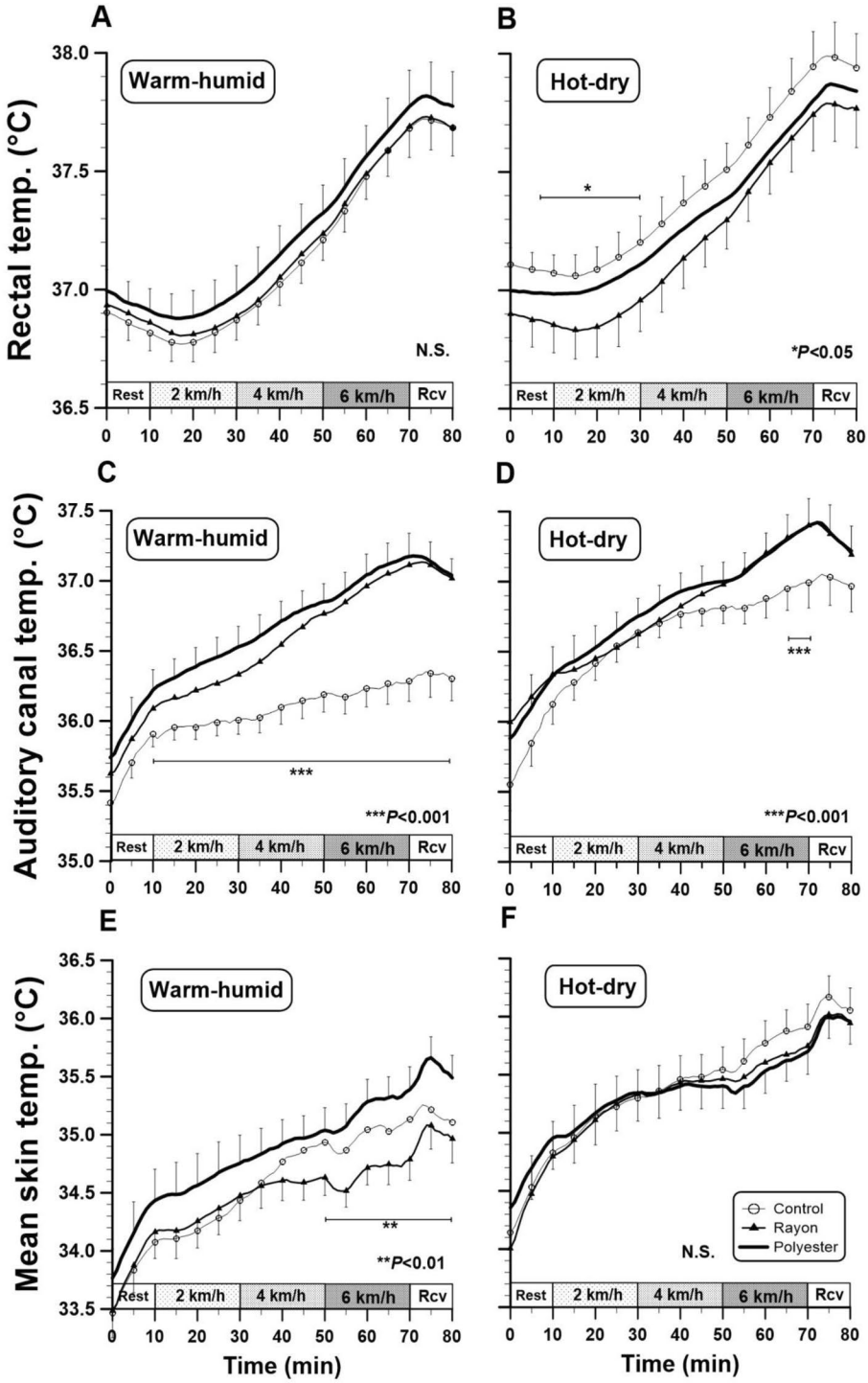

Fig. 1 Time courses of rectal temperature (**A** and **B**), auditory canal temperature (**C** and **D**) and mean skin temperature (**E** and **F**) in the warm-humid (30 °C and 70%RH) and hot-dry conditions (36 °C and 30%RH) at an identical WBGT of 27 °C

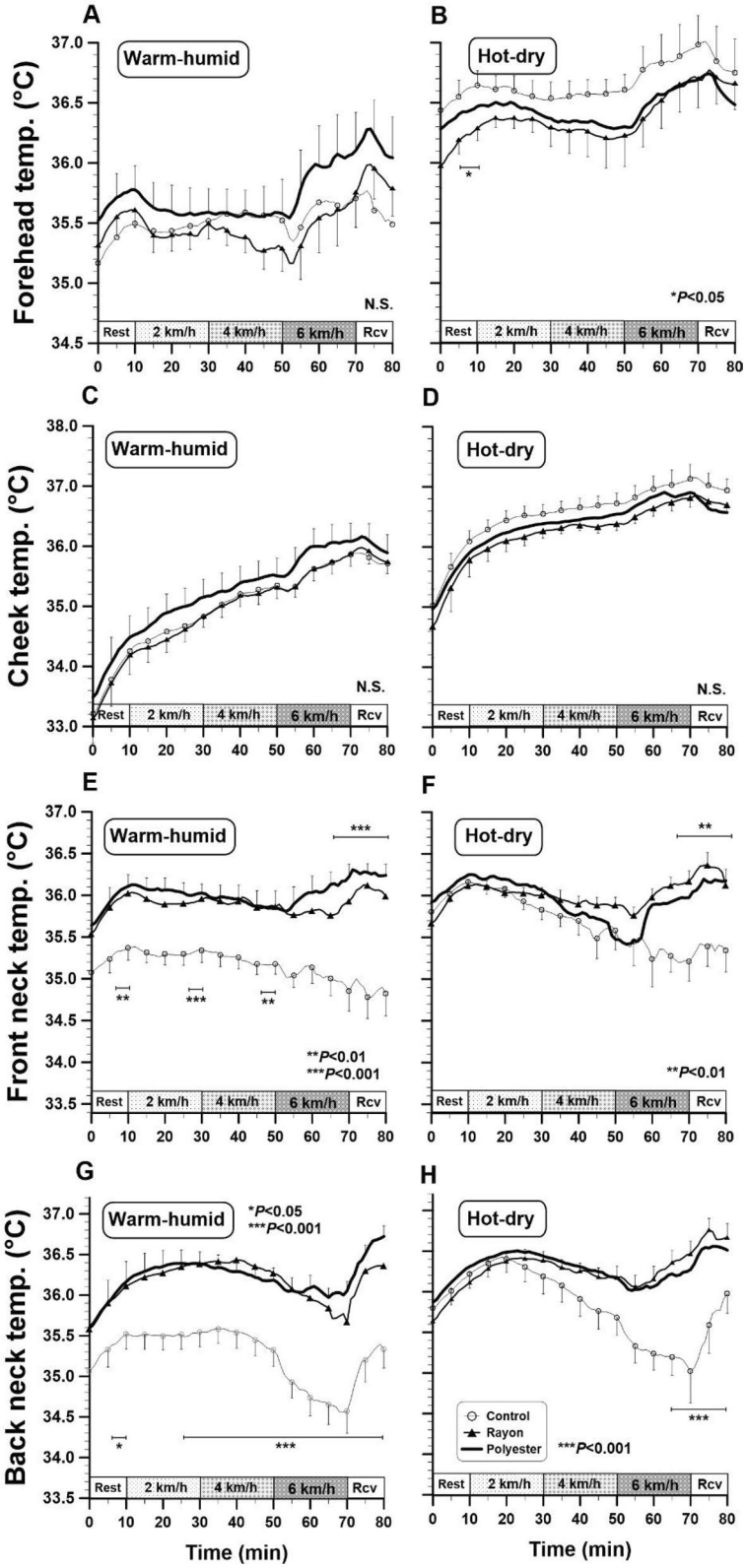

Fig. 2 Time courses of regional skin temperatures in the warm-humid (30 °C and 70%RH) and hot-dry conditions (36 °C and 30%RH) at an identical WBGT of 27 °C on the forehead (**A** and **B**), cheek (**C** and **D**), front neck (**E** and **F**), and back neck (**G** and **H**)

gradually increased for the two hijab conditions even during recovery, whereas the neck temperatures decreased for the control during recovery (Fig. 2E–H). The interaction between the environment and the hijab conditions was significant on the neck ($P < 0.05$).

Heart rate (HR)

Heart rate tended to be greater in the hot-dry environment compared to the warm-humid environment for the control and rayon condition, but such differences between the two environments were not significant (Fig. 3). Regarding the three clothing conditions, heart rate was greater for the polyester condition than for the control or the rayon condition, especially in the warm-humid environment (Fig. 3, $P < 0.05$). During recovery, heart rate was 96 ± 13 bpm for the control, 102 ± 15 bpm for the rayon condition, and 108 ± 19 bpm for the polyester condition in the warm-humid environment ($P = 0.002$, Fig. 3A), while heart rate was 107 ± 18 bpm for the control, 107 ± 18 bpm for the rayon condition, and 106 ± 16 bpm for the polyester condition in the hot-dry environment without any differences among the three hijab conditions ($P = 0.947$, Fig. 3B).

Total sweat rate (TSR) and local sweat rate (LSR)

Total sweat rate was greater in the hot-dry environment (192 ± 72, 265 ± 62, and 261 ± 63 g · trial^{-1} for the control, the rayon, and the polyester condition, respectively) than in the warm-humid environment (144 ± 46, 184 ± 43, and 202 ± 47 g·trial^{-1}) ($P < 0.01$ between the two environmental conditions, Fig. 4A). In the warm-humid environment, total sweat rate was significantly greater for the polyester condition than for the control and the rayon condition ($P = 0.049$). Sweat rate absorbed by the hijab materials was greater for the rayon condition (2.16 ± 1.23 g·trial^{-1}) than for the polyester condition (0.66 ± 0.85 g·trial^{-1}), especially in the hot-dry environment (Fig. 4B, $P = 0.013$). Local sweat rate on the back neck did not show any significant difference between the

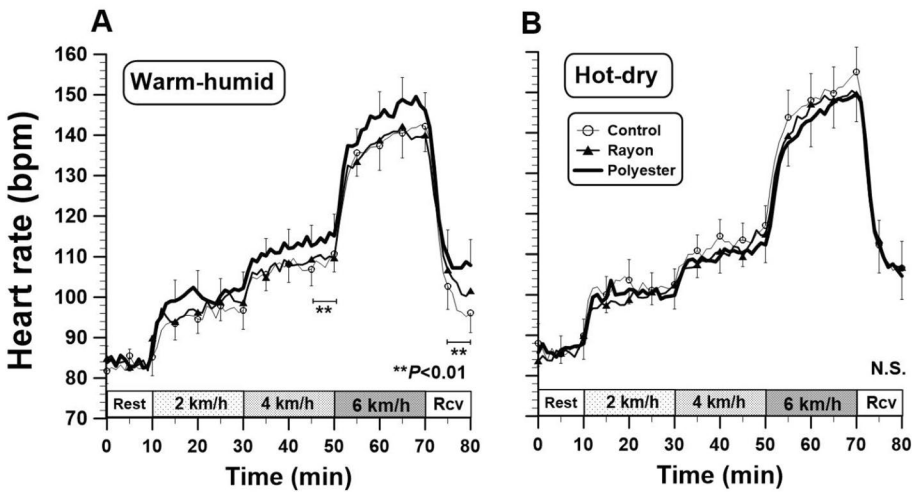

Fig. 3 Time courses of heart rate in the warm-humid (30 °C and 70%RH) (**A**) and hot-dry conditions (36 °C and 30%RH) (**B**) at an identical WBGT of 27 °C

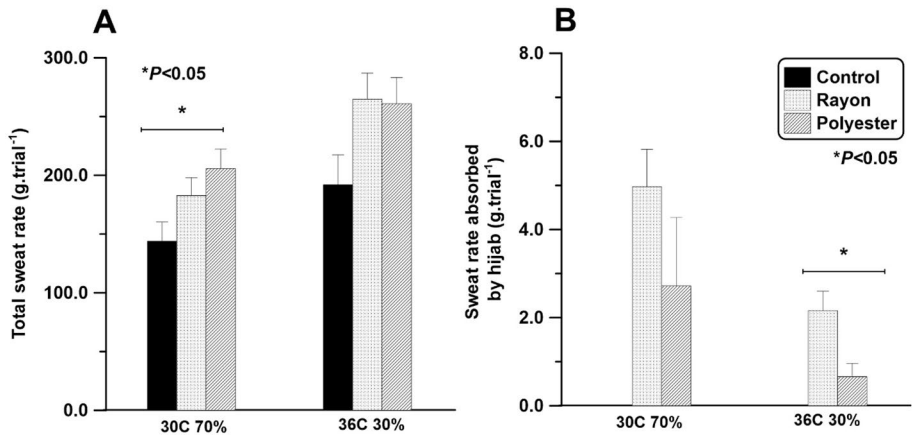

Fig. 4 Total sweat rate (**A**) and sweat rate absorbed by the hijabs (**B**) in the warm-humid and hot-dry condition

two environments or the three clothing conditions. However, local sweat rate on the back neck for the control was greater in the warm-humid condition than in the hot-dry condition.

Subjective responses on the whole body and the neck

Subjects felt warmer in the hot-dry condition than in the warm-humid condition ($P<0.05$), and felt warmer in the polyester condition than for the control at the end of exercise and during recovery ($P<0.05$). Similar tendencies were found for the neck part, especially in the warm-humid condition ($P<0.05$, Fig. 5). At the end of exercise, in the warm-humid condition, local thermal sensations on the neck were rated as 1.8 ± 0.7 (the control), 2.4 ± 0.6 (the rayon), and 2.9 ± 0.5 (the polyester) ($P=0.04$), while in the hot-dry condition were 1.9 ± 0.7 (the control), 2.4 ± 0.4 (the rayon), and 2.3 ± 0.7 (the polyester) with no differences among the three clothing conditions. In the hot-dry condition, there were no differences in thermal sensation among the three clothing conditions. Regarding thermal comfort, subjects felt more uncomfortable at the end of exercise and recovery in the warm-humid condition than in the hot-dry condition ($P<0.05$, Fig. 5). The polyester condition induced greater thermal discomfort during recovery than the other two conditions in the warm-humid condition on the whole body ($P=0.03$) and the back neck ($P=0.08$). Subjects felt more wet in the warm-humid condition than in the hot-dry condition at recovery and during the initial exercise ($P<0.05$), but the differences disappeared as the intensity of the exercise increased. Regarding the material effect, the polyester condition induced greater wet sensation during recovery than the rayon condition or the control in the warm-humid condition ($P<0.05$). There were no differences in thirst sensation between the two environments or the three clothing conditions.

Discussion

As very few studies on hijabs in terms of applied physiology were found, this research is original in evaluating the thermophysiological effects of the most commonly worn hijab materials in both warm-humid and hot-dry environments. Our three hypotheses

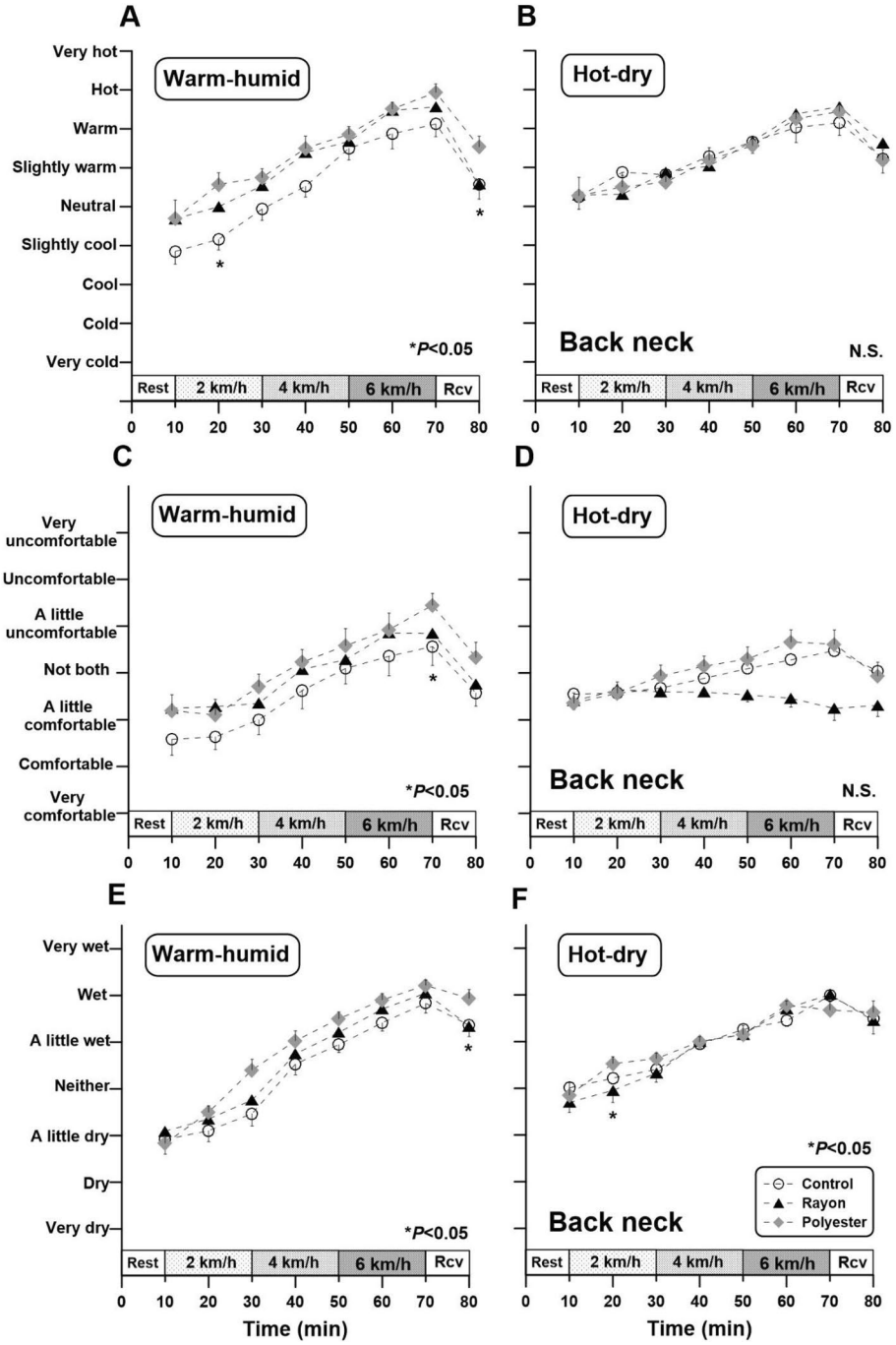

Fig. 5 Time courses of thermal sensation (**A** and **B**), thermal comfort (**C** and **D**) and sweat sensation (**E** and **F**) on the back neck in the warm-humid and hot-dry condition

were mostly accepted, but the results were dependent on whether the environment was warm-humid or hot-dry (Table 2). Mean skin temperature, total sweat rate, and subjective perceptions were higher and greater for the polyester hijab condition than for the rayon hijab condition in the warm-humid environment, rather than in the hot-dry environment. Secondly, the heat strain of wearers was greater for the hot-dry condition than

Table 2 Significant differences in thermal burden among the hijab materials and environments

Variables	Phase	Differences among the 3 clothing conditions (No hijab, polyester, and rayon)	Differences between warm-humid (WH) and hot-dry (HD)
Rectal temp	Exercise*	N.S.	N.S.
	Recovery	N.S.	N.S.
Auditory canal temp	Exercise	Polyester, Rayon > No hijab	WH < HD
	Recovery	Polyester, Rayon > No hijab	WH < HD
Mean skin temp	Exercise	Polyester > Rayon, No hijab (in the WH)	WH < HD
	Recovery	Polyester > Rayon, No hijab (in the WH)	WH < HD
Face temp	Exercise	N.S.	WH < HD
	Recovery	N.S.	WH < HD
Back neck temp	Exercise	Polyester, Rayon > No hijab	N.S.
	Recovery	Polyester, Rayon > No hijab	N.S.
Heart rate	Exercise	Polyester > Rayon, No hijab (in the WH)	N.S.
	Recovery	Polyester > Rayon, No hijab (in the WH)	N.S.
Total sweat rate		Polyester (and Rayon) > No hijab	WH < HD
Absorbed sweat by hijab		Polyester < Rayon	WH > HD
Back neck sweat rate	Exercise	No hijab > Polyester, Rayon	N.S.
	Recovery	No hijab > Polyester, Rayon	N.S.
Thermal sensation	Exercise	Polyester > No hijab (in the WH)	WH < HD
	Recovery	Polyester > No hijab (in the WH)	WH < HD
Thermal discomfort	Exercise	N.S.	WH > HD
	Recovery	Polyester > Rayon, No hijab (in the WH)	WH > HD
Sweat sensation	Exercise	N.S.	WH > HD
	Recovery	Polyester > Rayon, No hijab (in the WH)	WH > HD
Thirst sensation	Exercise	N.S.	N.S.
	Recovery	N.S.	N.S.

N.S. not significant

* At the end of exercise

for the warm-humid condition even though the WBGT of the two environments was identical. Thirdly, wearing hijabs induced greater head temperature, total sweat rate, and thermal sensation when compared to a condition with no hijab. We discussed the effects of hijab materials and the characteristics of heat stress in more detail.

Effects of hijab materials: cellulose vs. synthetic

We selected the most popular hijab materials based on the questionnaire conducted among hijab users in Indonesia and Malaysia. From the questionnaire, cellulosic materials (rayon) and polyester were chosen to be tested in the present study. A few studies have reported on appropriate hijab materials for sport activities, such as nylon, polyester, and acrylic (Baharudin et al., 2021), or poly-spandex, spandex balloon fabric, and Italian lycra fabric (Meilita & Berliana, 2020). Baharudin et al. (2021) found that polyester was the best material for exercise, while Meilita and Berliana (2020) suggested the Italian lycra material for hijab users. However, those studies were based on respondents' evaluations or skin temperature on the axilla (armpit). No studies reporting thermo-physiological influences in warm-humid and hot-dry environments were found. Several studies, even though the studies' concern was not the hijab material in hot environments, have

discussed the effects of clothing materials for general sportswear during sports activities. Gavin et al. (2001) found no significant differences between synthetic, cotton, and seminude fabrics during exercise. However, according to Brazaitis et al. (2010), skin temperature, sweat evaporation, and thermal sensation at rest were higher for the polyester shirt condition than the cotton shirt condition, which aligns with the findings of the present study. In the present study, we compared two hijab materials along with no hijab condition. Our findings revealed that the polyester hijab condition resulted in greater skin temperature, heart rate, and a warmer sensation compared to the rayon condition, particularly in the warm and humid condition.

The significant differences in physiological and subjective responses between the polyester and rayon hijab conditions can be explained with the differences in the physical properties of the two fabrics. The two hijab materials had its similar values in weight per surface area and thickness, but the polyester material had greater air permeability with shorter drying rate, smaller water absorption, and smaller water vapour permeability (Table 1). That is, the polyester material in the present study soaked and permeated smaller amount of body sweats, even though air was more permeable and water was dried faster when compared to the rayon hijab. In general, greater air permeability and drying rate of the polyester material allows greater heat loss through clothing than the heat loss in rayon with smaller air permeability (Epstein et al., 2013; Holmér, 2006). However, those benefits of polyester for the hijab, which encloses the head and neck, was not magnified in the present study. A pumping effect (increasing air movement between the skin and clothing layer, caused by body movement) is occurred around the trunk body region, especially the waist and legs during walking or exercise. Such air pumping is not less found around the head and neck, while sweating is greater for the head and neck than the waist or legs. Apart from air permeability, water vapor permeability is also one of the factors that affect the thermal comfort of clothing systems (Gidik et al., 2019). In this study, the rayon hijab had a higher water vapor permeability than the polyester hijab. In this regard, the rayon hijab with greater water absorption and water vapor permeability might result in better responses in skin temperature and subjective perceptions, when compared to the polyester with greater air permeability and drying rate.

An interesting finding was that most subjects preferred wearing the rayon hijab rather than not wearing any hijab because the rayon hijab effectively controlled sweating from the head and neck compared to the condition with no hijab, even though they felt warmer when wearing the rayon hijab compared to the condition with no hijab. Taken together, it is recommended to wear a hijab made of materials with greater water absorption and water vapor permeability rather than wearing a hijab with greater air permeability or not wearing any hijab.

Warm-humid vs. hot-dry environments

In the present study, two different environments of warm-humid and hot-dry combination, that are identical at the WBGT, were selected. Previous studies have found that greater air humidity under heat stress causes smaller sweating (Frye and Kamon, 1983; Jung et al., 2018; Keatisuwan et al., 1996; Ljungberg et al., 1979; Marimoto et al., 1967), which aligns with the result of the present study showing greater total sweating rate in the hot-dry environment than in the warm-humid environment (Fig. 5). This result can

be related to higher skin temperature for the hot-dry environment than for the warm-humid environment.

Studies that examined two environments with the same value in WBGT, have been reported. Ljungberg et al. (1979) compared the following two environments with the same WBGT at 32 °C: hot-dry (40 °C, 40%RH) and warm-humid (32 °C, 80%RH) and found greater sweat rate, $\_T_{sk,}$ and HR in the hot-dry condition than in warm-humid condition. In a similar way, Keatisuwan et al (1996) set a hot-dry condition (40 °C, 30%RH) and a warm-humid condition (31 °C, 80%RH) with an identical WBGT at 32 °C, which showed that sweat rate, HR, T_{re}, $\_T_{sk,}$ were higher in the hot-dry condition than the warm-humid condition. Even though two environments with an equivalent WBGT was not compared, Marimoto et al. (1967) found that sweat rate was higher in the dry environment than in the humid environment and Pulket et al. (1980) reported that higher skin temperature in drier environment under heat stress. We did not find any difference in rectal temperature, but the rest of the results are in agreement with the previous findings. Only for the thermal discomfort and sweat sensation, the subjects of the present study felt more uncomfortable and more wet in the warm-humid condition than in the hot-dry condition. One might inquire about the differences in thermal comfort despite no differences in core body temperature among the three clothing conditions. From an engineering perspective, particularly in human modelling, a key determinant of thermal comfort is core body temperature. However, this relationship is contingent upon the intensity of thermal stress and various individual factors. In the present study, the intensity of thermal stress was moderate, as evidenced by the rectal temperature remaining below 38 °C and the heart rate staying below 150 bpm, even at the end of exercise. Under conditions of moderate heat stress, subjective perceptions, primarily mediated through skin sensors, might serve as a more sensitive tool for discerning thermal stress compared to core body temperature, which primarily reflects overall body heat exchange. These findings suggest that subjective perceptions during mild heat stress in daily routines could be a primary determinant for thermoregulatory behaviours, such as altering clothing or utilizing air conditioning systems.

Even though the environments have the same WBGT value, the hot-dry and warm-humid environments affect body temperature regulation and thermoregulatory behaviour in different manners. When selecting better materials for the hijab in hot environments, the combination of the air temperature and humidity should be considered. The present study recommended materials with higher water absorption and water vapour permeability rather than materials with higher air permeability and drying rate for females in warm-humid environments.

Benefits of wearing hijabs in hot environments

Evidently, wearing the polyester hijab in hot environments yielded minimal advantages in terms of body temperature regulation, when compared to the condition without any hijab. In warm-humid environments, however, there were no significant differences between the control and rayon condition in thermal sensation, thermal comfort, and sweat sensation, whereas auditory canal temperature and total sweat rate were greater for the rayon hijab condition than for the control. These findings serve as a valuable guide for Muslim women who incorporate hijabs into their daily routines. Furthermore,

wearing a hijab might offer thermal protection to Muslim women, particularly in instances of excessive direct solar radiation upon the head. Given that prolonged exposure to sunlight is associated with increased skin aging and heightened susceptibility to skin cancer, the adoption of hijabs could potentially serve as a protective measure for the skin. Several studies have reported the merits of employing summer hats for shielding against UV rays (Backes et al., 2018; Gies et al., 2006). While the current study scrutinized the impact of hijab materials in two hot environments, future investigations encompassing diverse hijab styles, extended exposure durations, and intense solar radiation are necessary.

Conclusions

We found that wearing the rayon hijab resulted in lower skin temperature, lower heart rate, and improved thermal sensation compared to the polyester hijab. These differences were more pronounced in the warm-humid environment compared to the hot-dry environment. The significant differences can be explained by the moisture management properties of the materials, as the rayon fabric exhibited greater water vapor permeability and water absorption, but lower air permeability and a longer drying rate compared to the polyester fabric. Furthermore, the thermo-physiological burden was greater in the hot-dry environment than in the warm-humid environment, despite both conditions having an identical WBGT of 27 °C. Considering these findings, we suggest selecting hijab materials with higher water absorption and water vapor permeability for Muslim women living in warm-humid countries like Indonesia and Malaysia. However, other physical properties such as sun reflectivity or emissivity (e.g., colour or surface finishing) may be more significant factors when selecting hijab materials for Muslim women residing in hot-dry countries where solar radiation upon the head is strong. Further studies are needed to explore these aspects.

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Author contributions
SS participated in experiment, data analysis and carried out discussion and drafted the manuscript. MS participated in experiment, data analysis and discussion. SI participated in data analysis and discussion. JY devised study plan and participated data analysis, discussion and managed manuscript. All authors read and approved the final manuscript.

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

Declarations

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

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