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Influence of Stroller upon Thermal Insulation of Infant

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Abstract

In outdoor spaces, infants in strollers are significantly affected by thermal radiation from the ground surface due to their proximity to it. Infants are at increased risk of heat stroke while riding in a stroller. Infants are less thermally adapted to their environment and can consequently be considered to need protective measures against thermal environments. In order to treat strollers as clothing, in the present study, experiments were conducted to clarify the thermal environment of an infant riding in a stroller. Using an infant thermal manikin, the clothing area factor fcl and the clothing thermal insulation I_{cl} of the stroller were determined. The stroller clothing area factor fcl was 3.21 and the stroller clothing thermal insulation I_{cl} was 0.47 clo. Therefore, it can be inferred that strollers have a pronounced effect on the body heat balance between an infant and their environment.

Keywords

Heat Stroke, Infant, Stroller, Clothing Thermal Insulation, Thermal Manikin, Thermal Environment

1. Introduction

When the outdoor environment is hot, the effects of shortwave solar radiation from the sky and longwave thermal radiation from the ground surface are strongly apparent, bringing a significant risk of heat stroke and other heat-related disorders due to heat retention in the body. Shortwave solar radiation and longwave thermal radiation only work to increase the physiological and psychological temperature. Furthermore, due to the deterioration of the thermal environment of outdoor spaces caused by heat islands, health hazards and disorders of the human body may be increasing.

It has been shown that shortwave solar radiation has an effect on the thermal sense of the human body in outdoor spaces [1]-[8]. In addition, it has been demonstrated that the effects of direct and reflected solar radiation are significant in outdoor spaces, and that the outdoor thermal environment has a strong effect on the thermal sensation and comfort of the human body [9] [10] [11] [12] [13]. It has furthermore been demonstrated that shortwave solar radiation becomes significantly stronger as a factor of the thermal environment affecting the thermal environment evaluation index in outdoor spaces [7] [8]. Moreover, due to the albedo effect, a road surface can become heated to the degree whereby it cannot be touched directly. Ground surface objects with a high heat capacity are close to the human body and the angle factor is large. Accordingly, it has been clarified that the influence of longwave thermal radiation from ground surface objects becomes stronger due to the combined influence of solar radiation, even if the shortwave solar radiation is blocked, and that this is a factor of the thermal environment that affects the thermal environment evaluation index [10] [11] [12] [13]. Therefore, when the human body is facing the normal direction of the sun or is close to the ground surface, the heat acquisition of the body and the effect on the physiological and psychological temperature is significant. Accordingly, it is important to clarify this relationship with the physiological and psychological effect on the human body by quantifying the heat exchange from the environment to the body.

In outdoor spaces, one's position of facing the sun, one's proximity to the ground surface, the thermal environment are deemed problematic in a seated or decubitus position on the ground surface, or when riding in a wheelchair or stroller. Compared with able-bodied adults, physically challenged adults and infants have lower thermal adaptability to the environment, and it may be necessary to give sufficient consideration to their thermal environment. In the past, people had to carry infants when leaving the house, but with the increased availability of strollers, they have been freed from the heavy work of holding infants, and a social environment that facilitates outings has emerged. Physical barriers are gradually being removed, and roads and public facilities are becoming more accessible to wheelchairs and strollers. However, adults in wheelchairs and infants in strollers are susceptible to the effects of shortwave solar radiation and longwave thermal radiation.

In order to improve the thermal environment around their body, many people in wheelchairs are able to alert their guardians or carers about matters of behavioral thermoregulation. However, infants in strollers may have difficulty in alerting their parents about such issues because of their undeveloped volitional abilities.

Many people in wheelchairs are physically challenged, such as those with spinal cord injuries, or elderly people. They tend to be less adaptable to the thermal environment due to a reduced or partial deficit in sweating or blood flow regulation compared to able-bodied individuals. Guttmann *et al.* [14] have found that when persons with spinal cord injuries are exposed to low-temperature environments, they tend to dissipate excessive heat due to impaired vasoconstriction in peripheral parts of their limbs, while when exposed to high-temperature environments, they tend to retain heat in the body due to insufficient heat dissipation caused by impaired sweating. Iriki and Asaki [15] have found that due to age-associated decline in thermoreceptor and thermoregulatory functions, elderly people tend to be prone to shivering, non-shivering thermogenesis, and inadequate cutaneous vasoconstriction when exposed to cold environments, and to heat retention due to decreased sweating when exposed to hot environments.

It is not ethical to conduct experiments on people in wheelchairs regarding thermal environments based on heat balance. Against this background, Tsuchikawa *et al.* [16] have clarified the radiant heat transfer area and angle factor of a human body in a wheelchair. In outdoor environments during the summer, when the angle factor between the human body and the floor surface becomes significant and the ground surface temperature is high, heat acquisition by thermal radiation from the ground surface is significantly increased, and heat stroke and other heat-related disorders are a concern. Although it is essential to consider a person in a wheelchair's physical response to the thermal environment on an individual basis depending on their degree of disability, it may be possible to substitute human body coefficient values for an able-bodied individual in a chair-seated position for the physical heat transfer received by a person in a wheelchair from the thermal environment.

An infant in a stroller tends to easily warm up in hot environments and cool down in cold environments [17]. Therefore, infants' adaptations and sensory perceptions of their environment are believed to differ from adults' [17] [18]. Compared to adults, infants in strollers are less able to thermally adapt to their environment. Outdoor environments during the summer season are severe environments from the perspective of body temperature regulation, rendering it necessary to take protective measures against the thermal environment. It is essential to take into account how the thermal effects on infants differ from those on adults, and more care to thermal influence is needed.

It is not ethical to conduct experiments on infants in strollers regarding thermal environments based on heat balance. Therefore, to examine the thermal environment of infants, experiments and simulations using a human thermal model may be conducted by clarifying the human body coefficient values of infants. From this perspective, Kurazumi *et al.* [19] have developed a thermal manikin of an infant based on heat transfer area. Infant body coefficient values are indispensable for the control of an infant thermal manikin.

Focusing on the heat transfer area of infants, a reference infant body surface area has been measured [20]-[28]. The solar radiation area factor [29] and the clothing area factor of the infant body have also been measured [30] [31]. With regard to infant clothing, clothing insulation has been quantified [30] [32]. However, the only study conducted on the thermal environment and human body coefficient values for infants in strollers is that of Tsuchikawa *et al.* [29] on the solar radiation area factor. Therefore, it is essential to clarify the human body coefficient values of infants in strollers.

As mentioned above, infants in strollers can be greatly affected by shortwave solar radiation and longwave thermal radiation. Although strollers are shielded from shortwave solar radiation by shades, it is difficult to use a stroller with the shade on at all times due to issues such as ventilation. In addition, due to the short distance from the ground surface to the seat of the stroller, the passenger is deemed significantly affected by reflection from the ground surface. The seat of the stroller is subject to heat transfer by convection from the air around the stroller, and by shortwave solar radiation from the sun. This heat is then transferred to the infant's body by heat conduction via the body surface area in contact with the seat.

Considerable previous research addressing the influence on the human body in indoor spaces has focused on the chair-seated position, while much less research has attended to the human body heat balance and thermal conduction when evaluating the thermal environment. In spaces where air conditioning by thermal radiation and conduction occurs, the distance between the human body and the subject surface shrinks and the heat transfer area of the thermal radiation source (for example, the floor surface in the case of floor heating) increases. In addition, the heat transfer area on the human body side is relatively large in the floor-seated and decubitus positions, where much of the body surface is in direct contact with the floor surface [33]. Therefore, the effects of thermal conduction and thermal radiation are difficult to ignore, and the effects on the human body's thermal sensation and thermal comfort are stronger than in spaces where the normal air temperature is the sole control target [34] [35]. Kurazumi *et al.* [36] [37] have specified the positions for which the thermal environment must be evaluated, taking into account the influence of thermal conduction, and have clarified that evaluation, including with respect to heat conduction of the contact area between the floor surface and the human body, is necessary for a decubitus or floor-seated position. However, research regarding the human body heat balance that takes into account thermal conduction is rare. This is due to the lack of specification of the human body coefficient values necessary to calculate the body heat balance [38] [39], and the fact that the effect of heat conduction has not been incorporated into the thermal environment evaluation index.

Focusing on this point, Kurazumi *et al.* [40] have developed a thermal environment evaluation index that incorporates heat conduction in order to enable evaluation of the thermal environment in living spaces where people change their position and perform behavioral thermoregulation. Furthermore, verification tests to clarify the relationship between this thermal environment evaluation index and the physiological and psychological effect on the human body have been carried out, and its validity as an indoor environmental evaluation index that includes heat conduction from the floor surface in a living space has been demonstrated [41]. This verification experiment has clarified that heat conduction has a significant influence as an environmental factor that contributes to the thermal environment evaluation index.

The amount of heat exchange between an infant and the surrounding environment can be calculated for each conduction, convection, and radiation path, and the stroller itself can be treated as part of the infant's clothing. However, the clothing area factor fcl and the clothing thermal insulation I_{cl} for the treatment of the stroller as a garment have not been clarified at all. Therefore, the purpose of the present study was to clarify the clothing area factor fcl of infants in strollers by actual measurement, and then find the clothing thermal insulation I_{cl} of infants in strollers.

2. Clothing Area Factor

2.1. Clothing Area Factor Measurement Design

An experiment was conducted to clarify the clothing area factor of an infant riding in a stroller by actual measurement. Although the subject of such measurements should have been healthy infants, it would have been ethically impossible and practically difficult to perform actual measurements, so a human infant body model was used instead. A Nurse Training Baby (3B Scientific: W17002, Asian Body Care Model male) manufactured by Nihon 3B Scientific Inc [42] was used as the infant model, as shown in **Figure 1**.

The height of this Nurse Training Baby is about 50 to 60 cm. The 50th percentile data for the age of 1 to 2 months was extracted from the Ministry of Health, Labour and Welfare of Japan Survey of Male Infant Development [43], giving a height of 55.6 cm and a weight of 4.79 kg. Kurazumi *et al.* [19] have confirmed the validity of Nurse Training Baby as an infant human model. The body surface area of each part of the infant model is shown in **Table 1** [19].

Figure 1. Infant model. Posture is sitting on wooden frame support rack with bamboo material. Recline angle is 150˚.

Table 1. Characteristics of infant model.

Reagion	Surface area [cm^2]	Area ratio [-]	Area ratio [-]
Right head	256.29	0.123	0.238
Left head	240.53	0.115	
Right ventral trunk	155.25	0.074	0.302
Left ventral trunk	151.31	0.073	
Right dorsal trunk	154.99	0.074	
Left dorsal trunk	168.01	0.081	
Right upper arm	61.66	0.030	0.117
Left upper arm	60.71	0.029	
Right forearm	59.61	0.029	
Left forearm	60.87	0.029	
Right hand	34.80	0.017	0.041
Left hand	49.03	0.024	
Right thigh	146.78	0.070	0.240
Left thigh	159.07	0.076	
Right leg	91.86	0.044	
Left leg	105.32	0.050	
Right foot	67.78	0.032	0.062
Left foot	63.63	0.030	

Figure 2 shows the stroller, which is regarded as infant clothing. Only the seat is considered clothing. A Combi SUGOCAL 4 Wheels EggShock Light Plus (Combi Corporation) was used for the stroller. Standards for strollers include CPSA001 [44], EN1888 [45], ASTM F-833 [46], and BS7409 [47]. These standards specify structural safety features and the like, but only CPSA001 [44] standardizes the reclining angle of the stroller. The CPSA001 SG standard for stroller type A defined by the Consumer Product Safety Association [44] states that strollers for infants over one month of age who cannot support their own head, or strollers that can be used with the infant in a fully reclined position, should have a reclining angle of at least 150˚ for infants between one and four months of age, and a reclining angle of at least 130˚ for infants between four and 48 months of age. Therefore, in the present study, the backrest angle of the infant's chair-seated position was set to 150˚.

The actual measurement of the infant clothing area factor of the stroller was carried out using the methods of Yamato *et al.* [48] [49] and Kurazumi *et al.* [31] [50], which are modifications of the photographic method of Olesen *et al.* [51]. **Figure 3** shows the actual measurement coordinate system. The origin of the measurement coordinates was 0.05 m behind the umbilicus, which is the center point of the infant's body. Forty-eight points were measured using a combination of elevation and orientation angles. The elevation direction was measured

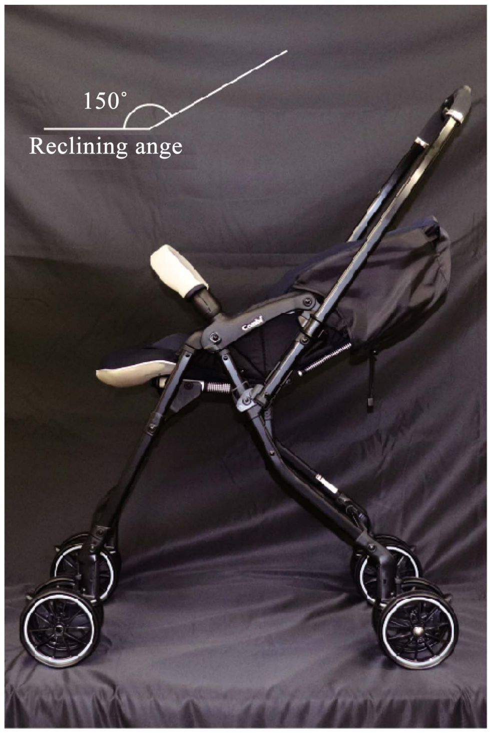

Figure 2. Stroller. Recline angle is 150˚.

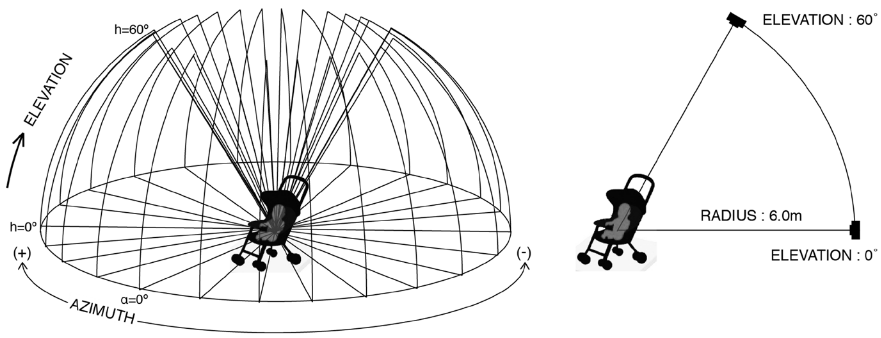

Figure 3. Coordinate system for measurement of clothing area factor.

0˚ and 60˚ from the coordinate origin. The infant model is not left-right symmetrical and, considering the established positions, the measured orientation angles were set at 15˚ intervals based on the median plane to enclose the infant model.

A full-size digital camera (Canon: EOS 5D, Canon: EF24 - 70 mm f/2.8) was used for photography. The focal length of the lens was fixed at 70 mm for the measurements. In the photographic method, the distance from the subject to the camera station must be as long as possible in order to minimize the shooting error to the extent possible. Accordingly, the measurement distance was set to 6.00 m, at which the projection area error was 1% or less in the measurements, as in Tsuchikawa *et al.* [29] and Kurazumi *et al.* [31].

To calculate the projection area of the subject in the captured image, a square piece of colored paper with a length of 0.15 m was placed next to the subject and photographed together with it, thereby forming a reference area facing the normal vector plane of the shooting elevation angle. Image processing software (Adobe: Photoshop CC2015) was used to calculate the projection area. To calculate the clothing area factor of the whole body, the calculation method of ISO 9920:2007 [52] was extended to the actual measurement points surrounding the whole body, and the clothing area factor of each measurement point was averaged.

2.2. Results and Discussion of Clothing Area Factor

Table 2 shows the calculation results of the clothing area projection rate for the infant in the stroller. The results are similar to those of Yamato *et al.* [48] and Kurazumi *et al.* [31] [50], who examined the relationship between the median plane left-right and coronal plane front-back orientation angles of the human body and the clothing area factor. Kurazumi *et al.* [31] [50] also found that in the leg-out seated position, in which the lower limb protrudes from the coronal plane, the clothing area factor was greater when the elevation angle was 60˚ than when it was 0˚. These results are consistent with the findings of the present study. The mean clothing area factor for the infant in the stroller was 3.21.

As mentioned in the introduction, the only study addressing the heat transfer area of infants in strollers is Tsuchikawa *et al.* [29], which has clarified the projected area factor with respect to shortwave solar radiation. The projected area in the naked state is the standard for the clothing area factor. Given that this was not actually measured, and the reclining angle of the stroller was 120˚, the measured values in the present study cannot be directly compared with those of

Table 2. Results of clothing area factors.

Azimuth [˚]	Stroller Elevation 0˚	Stroller Elevation 60˚	Azimuth [˚]	Stroller Elevation 0˚	Stroller Elevation 60˚
−180	3.19	2.85	180.00	3.19	2.85
−165	3.07	3.05	165.00	3.07	3.22
−150	3.55	3.46	150.00	3.47	3.58
−135	3.12	3.21	135.00	3.20	3.46
−120	2.97	3.05	120.00	2.97	3.47
−105	2.70	3.10	105.00	2.70	3.20
−90	2.28	3.40	90.00	2.40	3.65
−75	2.66	3.67	75.00	2.66	3.85
−60	2.85	3.82	60.00	3.11	3.93
−45	3.12	3.96	45.00	3.12	3.88
−30	2.48	4.11	30.00	2.48	3.68
−15	2.29	3.98	15.00	2.29	4.04
0	2.25	4.30	0.00	2.25	4.30
			fcl [-]	Stroller 3.21	

Tsuchikawa *et al.* [29]. Therefore, we estimated the clothing area factor by using the projected area of a naked infant whose reclining angle matched the elevation and azimuth angle of 60˚ [31], as a reference value for the values of 0˚ and 60˚ elevation in Tsuchikawa *et al.* [29]. The estimated clothing area factor for an infant in a stroller was 3.76. The results are generally consistent with the present study for a reclining angle of 150˚.

Examining heat exchange between the human body in a wheelchair and the environment, Tsuchikawa *et al.* [53] found that the clothing area factor of a naked adult in a wheelchair was 1.18. They also found the clothing area factor for an adult in a wheelchair to be 1.28. Tsuchikawa *et al.* [53] compared the clothing area factor of a clothed adult in a chair-seated position with that of Yamato *et al.* [48] in almost the same clothed state, and found that the wheelchair affected the heat balance of the human body sitting in it. In the present study, the clothing area factor was significantly higher than that of a naked adult in a wheelchair. Therefore, it can be inferred that strollers have a pronounced effect on the heat balance between the body of an infant in a stroller and the environment.

3. Clothing Thermal Insulation

3.1. Clothing Thermal Insulation Experimental Design

An experiment was conducted to clarify the clothing thermal insulation of an infant riding in a stroller by actual measurements. The actual measurement of the clothing thermal insulation was the same as that of Kurazumi *et al.* [32]. The clothing thermal insulation was computed using the calculation method of Kurazumi *et al.* [50], based on the theory of Seppanenn *et al.* [54].

The experiment was carried out in the environmental laboratory shown in **Figure 4**. The environmental laboratory was equipped with a conventional air conditioning system, and air intake and exhaust were conducted from the wall. The walls and ceilings were covered with thin curtains to give thermal environmental conditions, such that the mean radiant temperature at which the wall surface temperature was equal to the air temperature was the same as the air temperature.

The subject of the measurements should have been a healthy infant, but ethically this was not possible. Therefore, the experiment was conducted using an infant thermal manikin, the effectiveness of which has been confirmed in terms of body size and heat transfer area [19]. **Figure 5** displays the infant thermal manikin, and **Table 3** shows its body surface area [19]. The thermal manikin is designed to reproduce the 3D shape of the human body. However, the weight of the human body has not been reproduced. The same applies to the thermal manikin that have been developed until now. Many adult thermal manikins are commercially available, including those from Kyoto Electronics Manufacturing Co., Ltd. [55], Measurement Technology North West Thermetrics [56], Intec Co., Ltd. [57], and PT-Teknik [58], and Measurement Technology North West

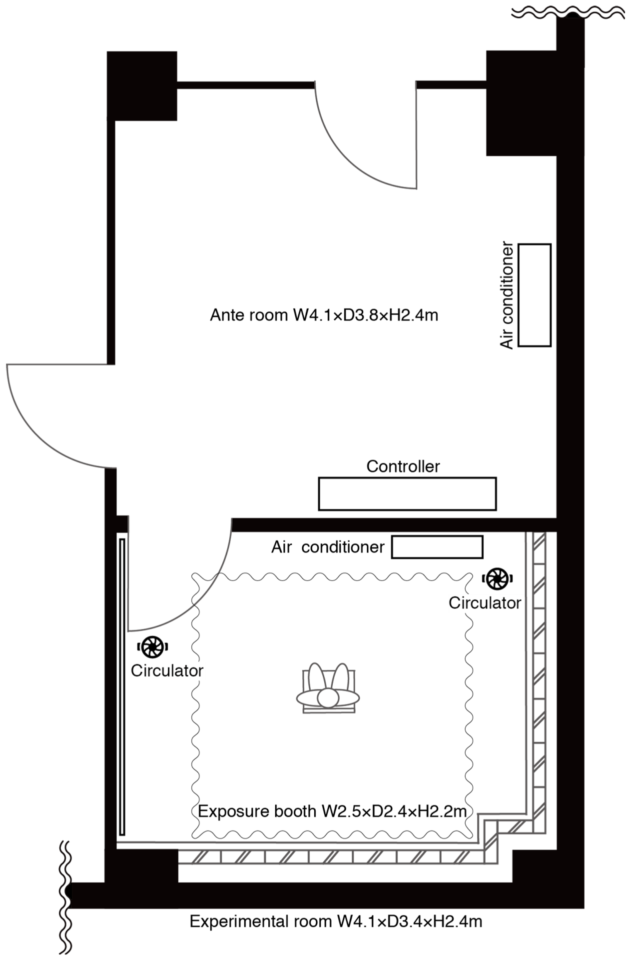

Figure 4. Plan of experimental setup where infant thermal manikin is exposed to thermal conditions.

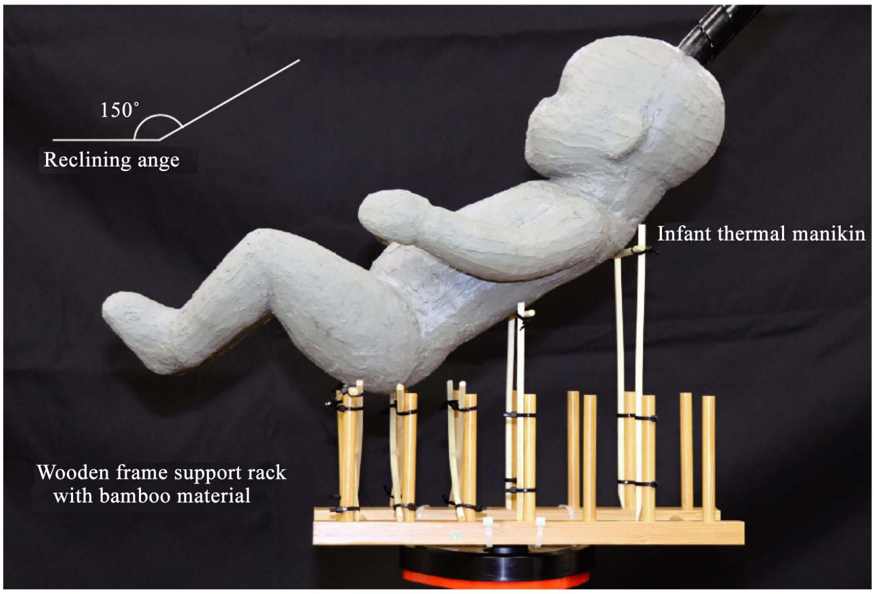

Figure 5. Infant thermal manikin. Posture is sitting on wooden frame support rack with bamboo material. Recline angle is 150˚.

Table 3. Characteristics of infant thermal manikin.

Reagion	Surface area [cm²]	Area ratio [-]	Area ratio [-]	Area ratio [-]	Area ratio [-]
Anterior head	352.99	0.157	0.240	0.240	0.240
Posterior head	187.97	0.083			
Ventral trunk	316.41	0.141	0.285	0.285	0.285
Dorsal trunk	324.69	0.144			
Right medial arm	54.39	0.024	0.060	0.120	0.159
Right lateral arm	79.88	0.036			
Left medial arm	54.48	0.024	0.060		
Left lateral arm	81.67	0.036			
Right dorsal hand	24.60	0.011	0.020	0.039	
Right palmar hand	19.51	0.009			
Left dorsal hand	23.80	0.011	0.019		
Left palmar hand	18.99	0.008			
Right anterior leg	158.52	0.070	0.128	0.258	0.316
Right posterior leg	131.23	0.058			
Left anterior leg	155.25	0.069	0.130		
Left posterior leg	136.64	0.061			
Right dorsal foot	32.57	0.015	0.030	0.058	
Right planter foot	34.75	0.015			
Left dorsal foot	30.23	0.013	0.028		
Left planter foot	34.22	0.015			

Thermetrics [56] also sell an infant thermal manikin. However, these are made based on the dimensions of the human body and not on the weight. Moreover, the weight of each part of the infant is unknown. Therefore, the weight of the thermal manikin is not taken into consideration in this study.

As described in the measurement of the clothing area factor, the clothing used in the experiment was only the part of the seat with which the infant in the stroller comes into contact. A Combi SUGOCAL 4 Wheels EggShock Light Plus (Combi Corporation) was used for the stroller. The position used in the experiment was set such that the angle of the backrest of the stroller was 150˚, as described in the actual measurement of the clothing area factor.

It has been confirmed that the infant thermal manikin of the present study [19] was identical in terms of shape and heat transfer area to the infant human model [42] described in the actual measurement of the clothing area factor [19]. Therefore, it is considered possible to use values clarified by actual measurement of clothing area factor for the calculation of the clothing thermal insulation.

The position in a naked state was maintained by placing the infant thermal manikin directly on a wooden frame with a support frame made of 5 mm breathable bamboo material, such that 0.05 m behind the umbilicus, which is the center point of the infant thermal manikin, was 0.90 m from the floor of the exposure space, and all surfaces were open to airflow. The surface of the infant thermal manikin was considered open to the atmosphere because the support frame has a small heat capacity, and during the experiment few parts were in contact with the manikin. To maintain the position of the infant in the stroller, the height of the stroller was adjusted using cardboard spacers on its wheels, such that 0.05 m behind the umbilicus, was 0.90 m above the floor of the exposure space. The stroller was deemed open to the atmosphere because the cardboard spacers have a low heat capacity and had little contact with the stroller's wheels.

Table 4 shows the set thermal environment conditions. This study was an exploratory and basic study aimed at clarifying the clothing thermal insulation of a typical infant. Accordingly, the thermal environment conditions were homogeneous, such that the mean radiant temperature, at which the surface temperature of the surrounding walls was the same as the air temperature, took three different temperatures of 20˚C, 22˚C and 24˚C, and was equivalent to the air temperature. Air velocity (a still condition of current under 0.2 m/s) and relative humidity (60% RH) were kept constant for all conditions.

The thermal environment parameters measured were air temperature, humidity, vertical temperature distribution, air velocity, and temperature of each surface of the room. Air temperature and humidity were measured with an Assmann ventilated psychrometer, air velocity with a non-directional hot-bulb anemometer, and vertical temperature distribution and surface temperature of each surface in the room with a 0.2 mm φ T-type thermocouple with a measurement interval of 5 seconds. Vertical temperature distributions were measured at heights of 0.0, 0.1, 0.3, 0.6, 0.9, 1.2, 1.5, 1.7, 2.0 and 2.2 m above the floor surface.

The surface temperature and heat loss of the infant thermal manikin were measured as the conditions on the infant thermal manikin side. For surface temperature and heat loss, power consumption was measured at a measurement interval of 5 seconds. The set thermal environment was maintained for at least 2 hours to ensure that the exposure space was in a steady state. The power level of the thermal manikin was then controlled to keep the surface temperature

Table 4. Experimental conditions.

Clothing	Air Temperature [˚C]: Ta	Air Velocity [m/s]: Va	Ralative Humidity [%]: RH	Mean Radiant Temperature [˚C]: MRT
Naked	20.0			
Naked	22.0			
Naked	24.0	<0.2	=50	=Ta
Stroller	20.0			
Stroller	22.0			
Stroller	24.0			

constant for more than 1 hour, so that it could reach a steady state. ISO 9920 [52] specifies an average skin temperature of 32˚C - 34˚C for thermal manikins as the experimental condition for the clo value. Oketani and Tokura [59] have found that the skin temperature of infants is higher than that of adults. This is because the skin thickness of infants is 1/2 to 1/3 of that of adults [60]. Therefore, the surface temperature of the infant thermal manikin was set to 34˚C.

After confirming that thermal equilibrium had been established between the infant thermal manikin and the ambient environment, and that the set thermal environmental conditions and the heat loss from the infant thermal manikin were in a steady state, the infant thermal manikin was exposed to the set thermal environmental conditions for 70 minutes. The following analysis uses 60 minutes of data, from 5 minutes after the start of the experiment to 5 minutes before the end.

3.2. Results and Discussion of Clothing Thermal Insulation

Table 5 shows the measurement results regarding the thermal environment conditions. The temperature for each experimental condition was controlled within a range of ± 0.1˚C, with a deviation of about 0.2˚C. There was a deviation of about 8% in relative humidity, but it was controlled within a range of ± 1.5%. Although the surface temperature of the surrounding wall surfaces had a difference of about 1˚C from the floor surface temperature, it was almost identical to the air temperature. Given that the angle factor of the infant was not known, it was not possible to determine an exact mean radiant temperature, but the area-weighted mean radiant temperature was almost identical to the air temperature. **Figure 6** shows the vertical air temperature distribution, including the air temperature and the floor/ceiling surface temperature. The air temperature ranged by about 1˚C. The air velocity remained under 0.2 m/s throughout the experiment. The thermal environment during each experiment generally satisfied the set conditions. ISO 9920 [52] states that the experimental conditions for the clo value are a difference between the air temperature and the mean radiant temperature of no more than 5˚C, air velocity being a calm airflow, and relative humidity being 10% - 70% with no variation during the experiment. Therefore, it can be said

Table 5. Results of thermal conditions.

Clothing	Air Temperature [˚C]: Ta	Air Velocity [m/s]: Va	Ralative Humidity [%]: RH	Floor Temperature [˚C]: Tf	Wall Temperature [˚C]: Tw	Ceiling Temperature [˚C]: Tc	Mean Radiant Temperature [˚C]: MRT
Naked	20.11 ± 0.05	0.03 ± 0.02	50.56 ± 0.50	19.49 ± 0.05	20.19 ± 0.05	19.84 ± 0.06	20.00 ± 0.05
Naked	22.08 ± 0.05	0.02 ± 0.02	49,86 ± 0.64	21.28 ± 0.05	22.20 ± 0.05	21.93 ± 0.05	21.99 ± 0.05
Naked	24.02 ± 0.05	0.03 ± 0.02	53.85 ± 0.35	23.02 ± 0.04	24.02 ± 0.06	23.93 ± 0.05	23.83 ± 0.09
Stroller	20.07 ± 0.10	0.04 ± 0.02	52.18 ± 0.57	19.56 ± 0.06	20.21 ± 0.10	19.93 ± 0.05	20.04 ± 0.07
Stroller	22.05 ± 0.10	0.04 ± 0.03	51.14 ± 0.35	21.32 ± 0.07	22.16 ± 0.07	22.05 ± 0.10	21.99 ± 0.06
Stroller	24.05 ± 0.06	0.03 ± 0.02	47.33 ± 0.47	22.65 ± 0.05	24.20 ± 0.07	24.09 ± 0.05	23.90 ± 0.06

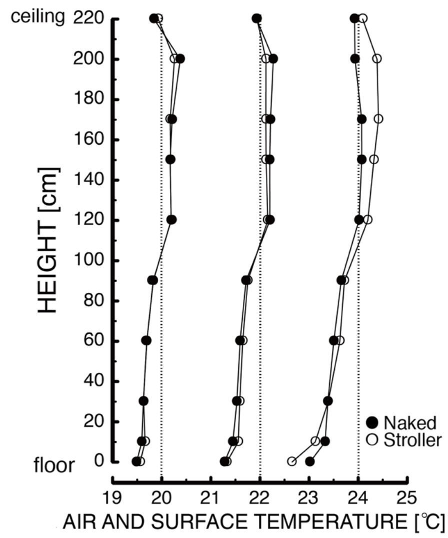

Figure 6. Distribution of vertical air and surface temperature in exposure space.

that the validity of calculating the clothing thermal insulation by the results of this experiment was confirmed.

The thermal insulation in a naked state I_a, the thermal insulation in a clothed state I_t, and the clothing thermal insulation I_{cl} are shown in **Figure 7**. The thermal insulation in a naked state I_a was 0.49 clo when the operative temperature was 20.11˚C. At 22.08˚C, it was 0.49 clo. At 24.02˚C, it was 0.45 clo. No significant difference by operative temperature was observed. Kurazumi *et al.* [32] [50] found that the higher the operative temperature, the smaller the difference with the surface temperature of the thermal manikin, with the effect of reducing the driving force of natural convection. In other words, they found that when the natural convection driving force is reduced, the updraft flow along the surface of the thermal manikin slows and the thermal boundary layer becomes thicker. However, in the temperature range of the present study, no temperature dependence was observed in thermal insulation in the naked state. The significance of the regression coefficient of the regression equation was tested by analysis of variance (ANOVA) ($p = 0.34$), yielding a result of $p > 0.05$, so the slope of the regression equation was judged not to be valid. Therefore, the thermal insulation of the naked body I_a could be expressed by an average value of 0.48 clo.

Fujii and Imura [61] found that the convective heat transfer coefficient of an inclined heating plate placed under natural convection is proportional to the (1/4) power of the product of the cosine component of the inclination angle h from the horizontal plane (cos h) and the gravitational acceleration g (g cos h). The JSME Data Book [62] also states that the convective heat transfer coefficient of an inclined heated cylinder placed under natural convection can be calculated by replacing the gravitational acceleration g of the Grashof number with the product of the cosine component of the inclination angle h from the horizontal plane (cos h) and the gravitational acceleration g (g cos h). In other words, it can be said that the convective heat transfer coefficient tends to decrease as the

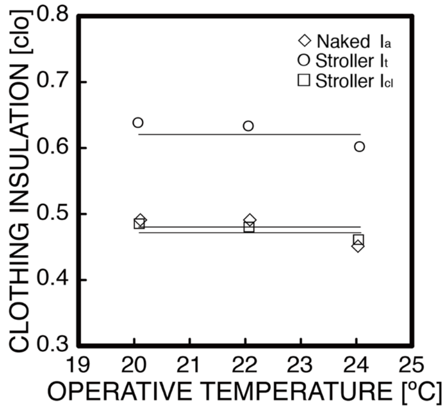

Figure 7. Relation between operative temperature and thermal insulation. I_a is thermal insulation of naked infant thermal manikin. I_t is thermal insulation of clothed infant thermal manikin. I_{cl} is clothing thermal insulation.

inclination angle of the heated object increases. Kurazumi *et al.* [32] measured the thermal insulation I_a of an infant when naked, finding that the insulation of a naked body with an inclination angle of 60˚ (reclining angle of 120˚) was 0.51 clo. In the present study, the insulation of the naked body of an infant with an inclination angle of 30˚ (reclining angle of 150˚) was 0.48 clo. It can be inferred that the overall heat transmission coefficient is larger in the case of a smaller clo value than for a larger clo value, because the operative temperature is almost the same at about 20˚C to 24˚C. The convective heat transfer coefficient was larger in the present study than in Kurazumi *et al.* [32] because the radiative heat transfer coefficient was considered almost the same in both states. These results are consistent with Fujii and Imura [61] and the JSME Data Book [62].

The thermal insulation I_t when riding in a stroller was 0.64 clo when the operative temperature was 20.07˚C. At 22.05˚C, it was 0.63 clo. At 24.05˚C, it was 0.60 clo. No significant difference by operative temperature was observed. As in the case of the naked body, the results suggest no temperature dependence on thermal insulation when riding in a stroller. The significance of the regression coefficient of the regression equation was tested by ANOVA ($p = 0.25$), yielding a result of $p > 0.05$, so the slope of the regression equation was judged not to be valid. Therefore, thermal insulation when riding in a stroller I_t could be expressed by an average value of 0.62 clo.

The clothing thermal insulation I_{cl} of the stroller was 0.48 clo when the operative temperature was 20.09˚C. At 22.06˚C, it was 0.48 clo. At 24.04˚C, it was 0.46 clo. No significant difference by operative temperature was observed. The significance of the regression equation regression coefficient of the clothing thermal insulation of the stroller was tested by ANOVA ($p = 0.00$), yielding a result of $p > 0.05$, so the slope of the regression equation was judged not to be valid. Therefore, the clothing thermal insulation of the stroller I_{cl} was 0.47 clo.

The thermal manikin controls only heating. Cooling is only natural heat loss. Consequently, if the difference between the surface temperature of the thermal manikin and the air temperature becomes small, the control of surface temperature becomes difficult and the error becomes large. Therefore, even in most of previous studies, experiments were conducted at temperatures below 21.2˚C that was defined by Gagge *et al.* [63]. The small deviation in this study is considered to be an error caused by the instability of natural heat dissipation.

As stated by Kurazumi *et al.* [32] [50], experiments on clothing thermal insulation using a thermal manikin require that the temperature of the outer surface of the clothing be accurately determined, and that consideration be given to the fact that the temperature of the outer surface of the clothing is lower than the surface temperature of the naked body. However, within the scope of the present study, the difference between the naked body surface thermal insulation and the stroller seat outer surface thermal insulation could not be accurately determined. In order to obtain the true value of the physical clothing thermal insulation in an experiment using a thermal manikin, it is essential to accurately determine the temperature of the outer surface of the clothing. However, in the present study it was also deemed possible to examine differences by clothing within a certain range, through a relative comparison of the clothing thermal insulation without examining the difference between the naked body surface thermal insulation and the stroller seat outer surface thermal insulation, because the thermal environmental conditions were exactly the same.

Examining heat exchange between the human body in a wheelchair and the environment, Tsuchikawa *et al.* [53] found that the clothing thermal insulation of a wheelchair was 0.16 clo. They also found that a wheelchair affects the heat balance of the body sitting in it. In the present study, the clothing thermal insulation was significantly higher than that of a naked adult in a wheelchair. Therefore, it can be inferred that strollers have a pronounced effect on the heat balance between the body of an infant in a stroller and the environment.

4. Conclusion

In outdoor spaces, infants riding in strollers are close to the ground surface, and the effects of thermal radiation from the ground surface are relatively significant, giving rise to concerns of heat stroke and other heat-related disorders. Infants riding in strollers tend to warm up in hot environments and cool down in cold environments, and their thermal adaptability to the environment is low, rendering it necessary to give sufficient consideration to the thermal environment. In order to treat a stroller as clothing, which provides heat shielding against the environment, we conducted an experiment to clarify the clothing area factor fcl and the clothing thermal insulation I_{cl} of a stroller using an infant thermal manikin. The stroller clothing area factor fcl was 3.21 and the stroller clothing thermal insulation I_{cl} was 0.47 clo. Thus, we found that strollers have a pronounced effect on the body heat balance between an infant and their environment. The results of this research can be used for the development of strollers and can contribute to the universal design of thermal environment planning for infants.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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