Comparison of different wheelchair seating on thermoregulation and perceptual responses in thermoneutral and hot conditions in children

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ABSTRACT

We examined the effects of 4 different wheelchair seatings on physiological and perceptual measures in 21 healthy, pre-pubertal children (9 ± 2 years). Participants were able-bodied and did not regularly use a wheelchair. Participants sat for 2 h in Neutral ($\sim 22.5\,°C$, $\sim 40\%RH$) and Hot ($\sim 35\,°C$, $\sim 37\%RH$) conditions. Four seating technologies were: standard incontinent cover and cushion (SEAT1); standard incontinent cover with new cushion (SEAT2) were tested in Neutral and Hot; new non-incontinent cover with new cushion (SEAT3); new incontinent cover and new cushion (SEAT4) were tested in Neutral only. Measurements included skin blood flow (SkBF), sweating rate (SR) and leg skin temperature (T_{legB}) on the bottom of the leg (*i.e.* skin-seat interface), heart rate (HR), mean skin temperature, tympanic temperature, thermal comfort, and thermal sensation. During Neutral, SkBF and T_{legB} were lower ($\sim 50\%$ and $\sim 1\,°C$, respectively) and SR higher ($\sim 0.5\,mg\,cm^{-2}\cdot min^{-1}$) ($p < 0.05$) with SEAT3 compared to all other seats. SkBF was $\sim 30\%$ lower ($p < 0.05$) for SEAT2 and SEAT4 compared to SEAT1. No other differences were observed between SEATs (all $p > 0.05$). During Hot, HR and temperatures were higher than in Neutral but there were no differences ($p > 0.05$) between SEATs. New cover and cushion improved thermoregulatory responses during Neutral but not Hot. An impermeable incontinent cover negated improvements from cushion design. Seat cover appears more important than seat cushion during typical room conditions.

1. Introduction

Individuals who use a wheelchair spend long hours in a seated position and develop significant skin wetness (maceration) in regions contacting seating surface. This wetness increases the risk of developing pressure injuries. Presently, no data exist as to the extent to which sweating occurs in children who use a wheelchair. Current guidelines and prevention strategies for pressure injuries are adapted from adult care, but are not evidence-based towards children in general [1,2].

Pressure injuries are a source of preventable harm and discomfort in individuals who use a wheelchair. Once formed, pressure injuries can be debilitating, affecting comfort, mobility and daily-life functionality with infected sores potentially leading to infection and even death [3]. The annual cost of treating pressure injuries is in the billions of dollars [3–7], while the prevention of pressure injuries, even if labour-intensive, can be more cost-effective [6]. The ongoing discomfort is often associated with reduced physical function and negatively affects

cognitive ability, leading to poor job or school performance. Wheelchair seat technology plays a crucial role in local heat dissipation and humidity management, both of which affect the development of pressure injuries.

Exacerbating factors which increase the risk of pressure injuries development include shear forces, elevated skin temperature, and importantly, skin-surface wetness [1,8,9]. Skin wetness is the product of unevaporated sweat, increasing its susceptibility to pressure injuries [10]. Indeed, the effects of humidity and temperature next to the skin surface are inextricably linked to concurrent soft tissue deformation [11]. However, extant data on skin wetness and thermoregulatory problems in children who use a wheelchair is extrapolated from data from adults with spinal cord injury. Importantly, children are characterized by higher skin temperature, yet lower sweating rate compared to adults [12,13]. As a result, this study aims to examine skin microenvironment and thermoregulatory mechanisms employed by children during different environmental conditions and using different

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wheelchair seating technologies.

Seat cushions greatly influence the microenvironment, resulting from an interaction between physiological responses, environmental conditions, and material properties of the cushion [14]. Several studies have examined the effects of different seat cushions on pressure-injury development, indicating that, in adults, pressure-reducing cushions resulted in a significantly lower pressure injury incidence than standard foam cushions [15–17]. Ferguson-Pell et al. [18] tested 32 available wheelchair cushions for their ability to dissipate heat and humidity and came to the conclusion that "Clearly, room for improvement exists in the design of cushion thermal dissipation performance" (p.954). Recently, intermittent electrical stimulation has been proposed as an approach to preventing deep tissue injury [19–22]. While this approach appears to be promising, it addresses the prevention of inside-out pressure injuries, rather than the common outside-in injuries. Importantly, all of the above studies were performed in adults and elderly individuals, and may not be applicable to children. Baharestani and Ratliff [23] highlight the need to develop age-specific measures for preventing pressure injuries in children.

Therefore, we sought to determine whether different wheelchair seating technologies affect physiological and perceptual responses in young children. To do this, we had four different seating systems that broadly-termed were: 1. Standard incontinent cover and cushion, 2. Standard cover, and newly designed cushion 3. Newly designed non-incontinent cover and newly designed cushion, and 4. Newly designed incontinent cover and newly designed cushion. We hypothesized that the newly designed cushion and covers would improve heat dissipation, as reflected by higher sweating rates and lower skin temperatures in the area in contact with the skin.

2. Materials and methods

2.1. Participants

All participants and parents were fully informed of the experimental methods and risks prior to volunteering. Parents and children provided verbal consent and assent, respectively. The study was cleared by the Bioscience Research Ethics Board at Brock University (BREB #14–051). All experimental protocols adhered to the guidelines set forth by the Declaration of Helsinki.

Twenty one healthy children (12 male/9 female) were recruited to participate in this study over 6 conditions with $n = 11$ for each condition (Table 1). Participants were able-bodied and did not regularly use a wheelchair. Physical characteristics are presented in Table 2. Participants were not diagnosed with any metabolic or cardiovascular disease, did not smoke and were not taking any medication. Participants were instructed to abstain from caffeine for 12 h and exercise for 24 h prior to testing. Additionally, the participants were instructed not to eat for 1 h prior to the testing session, but were encouraged to drink water *ad libitum*.

3. Seating types

3.1. Standard cushion and cover (SEAT1)

This assembly is comprised of a standard Invacare Matrx® Posture Seat Visco Foam (PSVF) cushion (Product ID: PSVF1816, Invacare, Mississauga, Canada) with standard Dartex™ fabric cover (Model: C-PSVF1816) (Table 3). Fabric provided to Invacare from Dartex™ coatings (Long Eaton, UK) and a standard order incontinence layer is attached in fabrication by Invacare to the Dartex™ Cover. Total dimension of the cushion and cover is 45.7 cm W x 40.6 cm D x 8.9 cm H.

3.2. Newly designed cushion, generic cover (SEAT2)

Custom made block style standard dimension 45.7 cm × 40.6 cm

Table 1
Study participation.

Participant	SEAT1		SEAT2		SEAT3	SEAT4
	Neutral	Hot	Neutral	Hot	Neutral	Neutral
1	x	x	x	x	x	x
2	x	x	x	x	x	x
3	x	x				
4	x	x	x	x	x	x
5	x	x				
6	x	x				
7	x	x				
8	x	x	x	x		
9	x	x	x	x		
10	x	x	x	x	x	x
11	x	x	x	x	x	x
12			x	x		
13			x	x		
14			x	x	x	
15			x	x	x	
16					x	x
17					x	x
18						x
19					x	x
20					x	x
21						x

(18″ x 16″) cushion alternative to the PSVF in SEAT 1. The cushion was made of 2.5 mm diameter full long-extrusion nylon 6,6 which was randomly wound to form a continuous sheet style material 8.9 cm thick. This sheet material was then heat cut to form closed ends on the cut extrusions. The seating block, as an alternative to the PSVF was cut to a 45.7 cm W x 40.6 cm D cushion, (Niagara Prosthetics & Orthotics, St. Catharines, Canada) (Fig. 1A) The same standard C-PSVF1816 Dartex™ cover with integrated incontinent cover was used to complete SEAT 2 (Table 3).

3.3. Newly designed cushion and newly designed cover (SEAT3)

The same 2.5 mm diameter full long-extrusion nylon 6,6 which was randomly wound to form a continuous sheet style material 8.9 cm thick (as used in SEAT2) was used again with a custom cotton/nylon blended cover. The custom cotton/nylon cover was fabricated without an integrated incontinence cover by sewing a standard shape 18″ x 16″ cushion cover from purchased woven bolt material 23% Nylon, 74% Cotton, and 3% Spandex with a 110 gsm weight (Niagara Prosthetics & Orthotics, St. Catharines, Canada) (Table 3). The new cushion and cover is easily washable and dry-able in short time frames such that there is no requirement for an impermeable incontinence cover to protect the cushion from damage.

3.4. Newly designed cushion and newly designed incontinence cover (SEAT4)

While the new cushion is easily washable, feedback from families at Niagara Prosthetics and Orthotics indicated that an incontinence cover was necessary. As such, SEAT 4 is a replica of SEAT 3 with the addition of a unique incontinence cover (Table 3). The cover was fabricated from bolt sheet material and sewn into a standard 18″ x 16″ cover. The material is designed to be unidirectionally water resistant (thus protecting the cushion) while breathable for air flow. The seams were sealed using Seam Seal™ thread treatment post fabrication. The bolt sheet material is a coated fabric similar to the material used in SEAT 3 (without Spandex due to the incompatibility with the stretch properties of the coating) with a polyurethane-based treatment to the inside surface of the fabric in a microscopic structure (Model number KBTRPM250P-F15-B16). Fabric is 75% Nylon and 25% Cotton and 115 gsm weight. The material is not a membrane based material such as Gore-Tex™.

Table 2
Participant characteristics. Data are mean ± SD.

	Total (N = 21)	Seat 1	Seat 2	Seat 3	Seat 4
Male/Female	12/9	6/5	6/5	7/4	7/4
Age (years)	9.5 ± 1.3	9.3 ± 1.6	9.4 ± 1.2	9.4 ± 1.2	9.6 ± 1.1
Mass (kg)	40.7 ± 8.3	40.2 ± 9.3	41.1 ± 11.3	38.9 ± 8.2	40.2 ± 6.4
Statue (m)	1.47 ± 0.98	1.48 ± 0.92	1.49 ± 0.9	1.45 ± 0.88	1.49 ± 0.74
BMI	18.8 ± 3.4	18.4 ± 3.7	18.5 ± 4.1	18.5 ± 4.7	18.1 ± 4.9
Pubertal stage	1(n = 17), 2(n = 3)	1(n = 8), 2(n = 3)	1(n = 8), 2(n = 3)	1(n = 8), 2(n = 3)	1(n = 8), 2(n = 3)
BF%	17.7 ± 4.1	18.4 ± 4.5	17.9 ± 3.9	18.7 ± 4.3	17.9 ± 4.7
Blood pressure (mm Hg)					
Systolic	85 ± 4	86 ± 4	85 ± 4	85 ± 4	85 ± 5
Diastolic	47 ± 4	48 ± 4	47 ± 4	46 ± 5	46 ± 4

BMI = body mass index; BF% = body fat percentage.

Table 3
Seating cushion and cover permutations used in this study.

	SEAT1	SEAT2	SEAT3	SEAT4
Cushion	Standard foam	New nylon	New nylon	New nylon
Cover	Standard incontinent	Standard incontinent	New cotton	New incontinence

3.5. Instrumentation and experimental procedures

Upon arrival at the laboratory children changed into provided clothes for the study (generic t-shirt and shorts of appropriate size) and completed a pubertal staging questionnaire (often with parental assistance). Body mass and standing stature were measured, along with skinfold thicknesses for the calculation of body fat percentage [24].

Participants were then instrumented with a 3-lead electrocardiogram (ECG; BioAmp, AD Instruments, Colorado Springs, CO, USA) to measure heart rate. Mean whole body skin temperature ($\bar{T}_{sk}$) was recorded from the weighted average of 4 T-type thermocouples (PVC-T-24-190, Omega Environmental Inc., Laval, QC, CA) placed on the chest, forearm, thigh, and calf [25]. Temperature from the top of leg (quadriceps, T_{legT}) and bottom of leg (hamstring, T_{legB}) was recorded from T-type thermocouples (PVC-T-24-190, Omega Environmental Inc., Laval, QC, CA). An index of core temperature was obtained from tympanic temperature (T_{ty}) using a thin and small flexible probe (Smiths Medical, ASD) on the left side. These were self-inserted until the probe touched the tympanic membrane, moved slightly away from it, and held in place with cotton wool and taped in place with hypoallergenic surgical tape (Transpore, 3 M Canada). Tympanic temperature has been related to both skin and environmental temperatures [26], but is influenced by warm environmental conditions. Therefore, in lieu of absolute T_{ty}, changes in T_{ty} were quantified (ΔT_{ty}) to reflect changes in core temperature. Each probe was used for one trial and then disposed.

Participants were seated in a custom-built wheelchair (Fig. 1B), the seating of which has two, 4 cm diameter holes (Fig. 1C), to allow for measurement of skin blood flow and sweating rate from the underside of the leg and were plugged with the appropriate cushion and cover material until sampling for set time periods. Skin blood flux was recorded using laser speckle contrast imaging (moorFLPI-2, Wilmington, DE, USA) from the underside of the right leg. Skin blood flux data were normalized for mean arterial pressure and are presented as cutaneous vascular conductance (CVC). Local sweating rate was measured from the underside of the left leg, using sweat collection patches that are applied directly to the skin area of interest. Absorbent patches, consisting of 4.7 × 3.1 cm filter paper, were affixed to the skin for 15 min periods with Tegaderm (3 M Medical Technologies, Minneapolis, MN). Subsequently, they were placed in a sealed plastic bag and weighed within 90 min of collection (XSR105 Analytical balance, 0.01 mg readability).

Thermal comfort (TC) (4 point scale, Comfortable to Very uncomfortable) and thermal sensation (TS) (7 point scale from Cold to Hot) were obtained to gauge participant perception of the thermal environment [27]. Blood pressure was measured by manual auscultation in duplicate by the same investigator.

All procedures were performed with the participants resting in a seated position for 2 h of data collection. Participants were able to read, watch a movie, or use cell phones/tablets. The six experimental sessions were identical in protocol, with different environmental conditions. In the four Neutral trials (all four seating types), ambient temperature
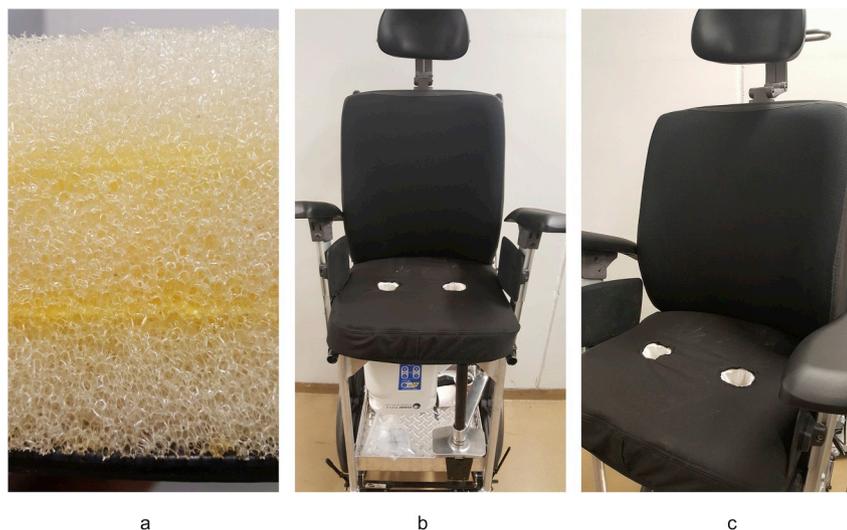

Fig. 1. Photographs of new cushion and wheelchair set up. Panel A shows the structure of the new seat cushion. Panel B shows the wheel chair with the laser speckle contrast image attached. Note that supports for participant's legs were removed for clarity. Panel C shows the 4 cm diameter holes for the measurement of skin blood flow and the placement of sweat rate patches.

a   b   c

(T_{amb}) and relative humidity were $22.4 \pm 0.1 \,^{\circ}\text{C}$ and $40.4 \pm 6.5\%$. In the two Hot trials (seats 1 and 2) T_{amb} and relative humidity were $34.9 \pm 0.3 \,^{\circ}\text{C}$ and $36.6 \pm 6.2\%$. The order of the Neutral and Hot trials were counterbalanced among participants and all sessions were performed at the same time of day for each participant. Seating types were performed in order. Experimental trials for each participant were performed on different days and separated by at least 48 h to ensure no potential confounding effects of the HOT trial on thermophysiological measurements. We hypothesized that all three custom seats would provide enhanced physiological and perceptual responses over SEAT1. It was apparent that during the Hot condition, there was no added benefit of SEAT2 over SEAT1 (see results). Therefore, SEAT3 and SEAT4 were not tested in the Hot condition.

3.6. Data collection

The ECG recordings were collected continuously at 1 KHz (LabChart Pro v.8, PowerLab, ADInstruments). Temperature data (T_{tym}, $\bar{T}_{sk}$, T_{legT}, T_{legB}) were collected continuously at 4 Hz (LabChart Pro v.8, PowerLab, ADInstruments) using T-type thermocouples and thermocouple meter (TC-200, Sable systems, Las Vegas, NV, USA). Temperature Δ values were calculated from a 5 min resting period of data at the start of the trial and each data point presented is 1 min of data from the corresponding time point e.g. 5 min, 10 min, etc. Skin blood flux data were collected continuously at 0.1 Hz (moorFLPI-2, Wilmington, DE, USA). Local sweating rate was determined by patch weight increase (to 0.0001 g) from the dry weight and expressed per minute. Four patches were placed at the 10, 35, 70, and 100 min time points and left in place for 15 min. Blood pressure and perceptual measures (TC and TS) were collected at 10, 20 min, and every 20 min thereafter.

3.7. Statistical analysis

Data were normally distributed as assessed by Q-Q plots, and skewness and kurtosis measures. Normality was defined as a skewness value less than ± 3 and a kurtosis value less than ± 9. A repeated measures 2-way ANOVA was used to examine outcome variables or changes in outcome variables (from baseline) with each seat over time (within subjects), for Neutral and Hot trials (separately), with a Bonferroni *post-hoc* correction for multiple comparisons. Anthropometric data are presented as mean $\pm$ SD and, all other data are presented as mean $\pm$ SE. Data were analysed using SAS (SAS institute, Toronto, Canada) and GraphPad Prism 6 (GraphPad Software Inc., La Jolla, CA, USA) and statistical significance was defined as $p < 0.05$.

4. Results

4.1. Temperature measurements

$\Delta\bar{T}_{sk}$ presented with no main effects (all $p > 0.3$) in the Neutral condition, while in the Hot condition there was a main effect for time ($p < 0.001$), but not for seat, and no interaction ($p > 0.5$) (Fig. 2).

During the Neutral condition, there were no main effects (seat $p > 0.8$, time $p > 0.9$, or interaction $p > 0.9$) in ΔT_{ty} among 3 seating combinations (Fig. 3A). In the Hot condition, there was a main effect for time ($p = 0.007$) reflecting an increase in ΔT_{ty}, but not for seat, and no interaction (both $p > 0.9$) (Fig. 3B).

In the Neutral condition, there were main effects for seat ($p < 0.001$) and time ($p < 0.001$) for ΔT_{legB}, but no interaction ($p > 0.9$) (Fig. 4A). Temperatures were significantly lower with SEAT3 compared to all other seating types. There were no differences in ΔT_{legT} during the Neutral condition (all main effects $p > 0.1$) (Fig. 4C). For both ΔT_{legB} and ΔT_{legT} in the Hot condition, there were main effects for time (both $p < 0.001$), but not for seat, and no interaction (all $p > 0.8$) (Fig. 4B and D).
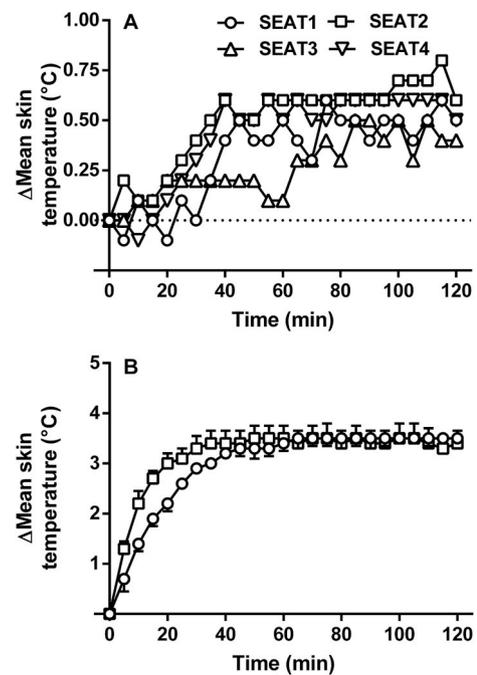

Fig. 2. Mean whole body skin temperature. Panel A presents the data for the 4 Neutral conditions. Panel B shows the data from the 2 Hot conditions. Error bars are omitted from panel A for clarity.
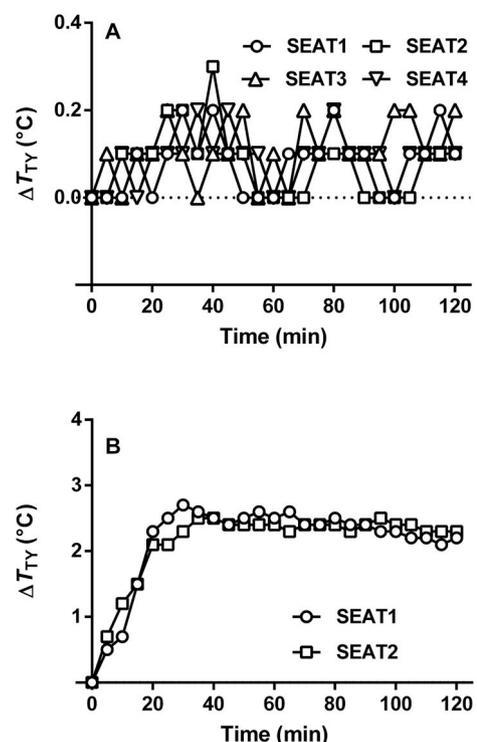

Fig. 3. Change in tympanic temperature for the Neutral (A) and the Hot (B) condition. There were no differences among the seat types for either condition. Error bars are omitted for clarity.

4.2. Thermoregulatory responses

For SR on the bottom of the leg, during the Neutral conditions, there were main effects for seat ($p = 0.012$), but not for time or interaction (both $p > 0.45$) (Fig. 5C) with SR being higher with SEAT 3 compared with the other seating types. There were no effects for the SR on the top
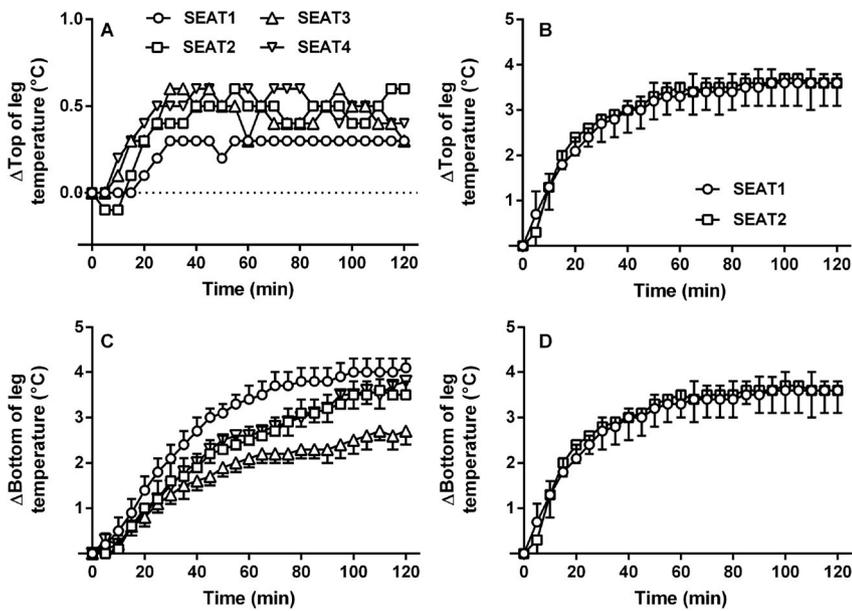
Fig. 4. Change in top and bottom of leg temperatures. Panels A and B present the data for the top of the leg from the Neutral and Hot conditions, respectively. There were no differences between the seating types for either condition. Error bars are omitted from panel A for clarity. Panels C and D are for the bottom of the leg from the Neutral and Hot conditions, respectively. Temperature was significantly lower with SEAT3 compared to the other seating types. There were no differences in bottom of leg temperature between the seating types in the Hot condition.
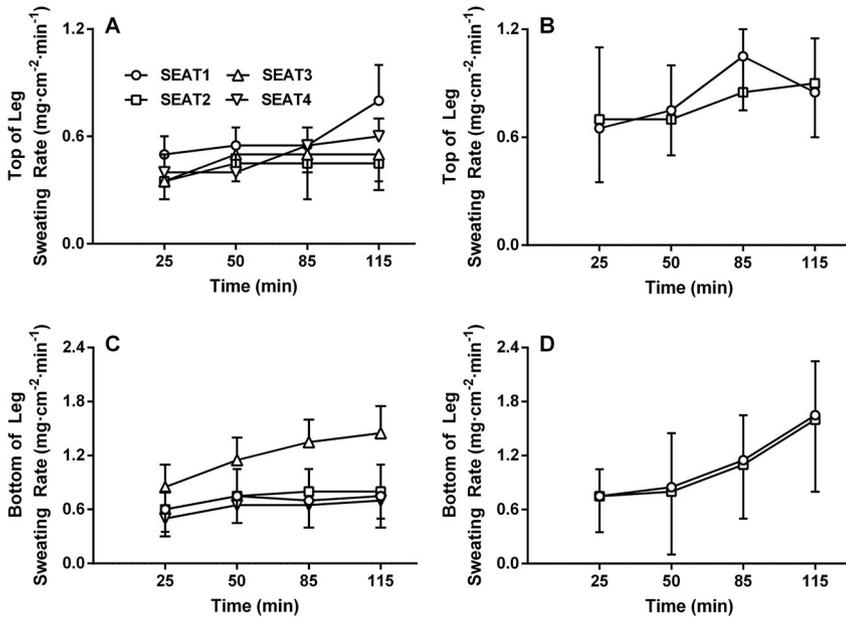

Fig. 5. Sweating rate data from the top of the leg in the Neutral (A) and Hot (B) conditions, and bottom of the leg in the Neutral (C) and Hot (D) conditions. There were no statistical differences in sweating rate on the top of the leg in either the Neutral of Hot conditions. Sweating rate on the bottom of the leg was higher with SEAT3 compared to the other seating types (C). There were no differences in sweating rate between the seating types in the Hot condition.

of the leg in the Neutral trial, nor were there any main effects for SRs during the Hot conditions (Fig. 5B).

For skin blood flow in the Neutral condition, there were main effects for seat, time, and interaction (all $p < 0.001$) (Fig. 6A). Compared with SEAT1, skin blood flow was lower in SEAT2 and SEAT4, and lowest with SEAT3. In the Hot condition, there was a main effect for time ($p < 0.001$), but not for seat ($p = 0.18$) or interaction ($p > 0.9$) (Fig. 6B).

There were no main effects (all $p > 0.4$) for systolic blood pressure, diastolic, or heart rate during the neutral condition (Fig. 7A, C, E). There were also no main effects (all ≥ 0.09) for heart rate (Fig. 7B) and systolic blood pressure (Fig. 7D) in the Hot condition. However, for diastolic blood pressure there was a main effect for time ($p = 0.04$), but not for seat or interaction (both $p > 0.2$) (Fig. 7F).

4.3. Perceptual responses

During both the Neutral and Hot trials there were no differences in TC or TS among the seating types ($p > 0.9$) (Table 4).

5. Discussion

This study aimed to examine the effects of different wheelchair seatings (cushion and cover) on physiological and perceptual measures of thermoregulation in children. We found that the cushion had little effect on thermoregulatory measures; however, the newly designed cushion-and-cover combination (SEAT3 with new cushion and breathable cotton cover) had the greatest positive effect, as reflected by the skin temperature, local sweating rate and skin blood flow response. The physiological and perceptual responses in SEAT2 (new cushion) and SEAT4 (new cushion and incontinence cover) were not different from the standard cushion and seat covering currently available on the market (SEAT1).

Skin moisture increases pressure injury risk by increasing friction, which results in more tissue shear, and by causing moisture-associated skin damage, making the tissue more susceptible to pressure injury. We observed an increase in SR with SEAT3; while this might seem counter-intuitive (i.e. more sweating would lead to more wettness) the breathable properties of the cotton cover likely facilitated higher
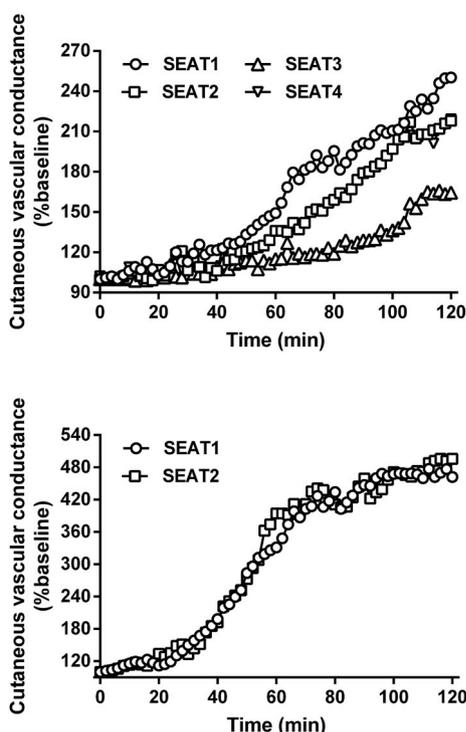
Fig. 6. Cutaneous vascular conductance data for the Neutral (A) and the Hot (B) conditions. In the Neutral condition, cutaneous vascular conductance was lower in SEATs 2 and 4 compared to SEAT1; SEAT3 was lower than all other seating types. There were no differences between the seating types in the Hot condition. Error bars are omitted for clarity.

evaporative cooling, which in turn led to increased sweating rate and better heat loss. This is reflected in the lower SkBF and T_{legB} for SEAT3 compared with all other seating combinations. Thus, positive effects achieved through simple modification of the seating type are likely to reduce the risk of pressure injury development. While we examined healthy children, our finding may be important for those with spinal cord injury, as it is well established that those with spinal cord injury have reduced sweat gland activity and response to increased temperature [28], and thus would allow for better heat loss despite reduced gland activity.

We also noted in SEAT3 that there was a lower skin temperature on the underside of the leg (i.e. side in contact with the seat). These data suggest that the new seating reduces the local heat storage, likely due to enhanced airflow and heat dissipation. It appears that the incontinence seat covers impair heat dissipation to a greater extent than the cushion. While SEAT3 was the most desirable from a thermophysiological standpoint, user feedback reported that the lack of an incontinence (fluid resistant) cover was a major drawback. This is despite the new cushion being made from nylon woven open cell foam, which is washable both by hand and in standard household washing machines.

We observed no differences in whole body skin temperature, core temperature, blood pressure, and heart rate. Whilst we did observe local changes in temperature, blood flow, and sweating in the areas in contact with the new seating, we did not see differences between seats in those regions not in contact with the seat (including top of the leg). Thus, the effects of the seat cover and cushion were limited to the interface of the person and the technology. This is likely the reason we observed no differences in perceptual measures between conditions. These data indicate that while the type of seating improved thermophysiological responses (SR, SkBF, and T_{LegB}), these did not alter the thermal perception of the children. This is likely related to the fact that we observed no differences between seats in the systemic/whole body responses (T_{sk}, T_{ty}, HR). Indeed, the scales are gross indices of thermal

comfort and are not focused on the local response (seated area). It should be noted that the current study was only 2 h in duration. It is possible that, if the participants were in SEAT3 (the seating that demonstrated the greatest benefit in terms of heat dissipation) for a longer time, as is typical for children who use a wheelchair (i.e. most of the day), perceptual responses to the new seating may be more noticeable.

Surprisingly, we found no differences between SEAT1 and SEAT2 in the Hot conditions for any of the measures. This could be that the magnitude of the heat stress in the Hot conditions was so great that any beneficial effects of the newly designed cushion were masked under such strong environmental stress (e.g. see figures on SkBF and T_{legB}). Indeed, there were clear, positive differences under Neutral conditions for T_{legB}, and SkBF.

A limitation of this study is that we tested healthy children who do not use wheelchairs. Future studies should aim to examine children who use a wheelchair. Potentially, there are numerous reasons for wheelchair use and the consequential effects of this on physiological responses may vary. For instance, it is known that in adults with spinal cord injury, sweating rate below the level of the lesion is often greatly reduced, if not, abolished [29–31]. This has a marked effect on the individual's ability to adequately thermoregulate [28,32,33], and the data from the present study clearly demonstrate a significant effect of seating materials on sweating rate and skin temperature.

5.1. Perspectives

These data indicate seat covers play a significant role in skin temperature and moisture, both risk factors for pressure injury development. This is due to the need for seat covers to prevent potential damage to seat cushions during a bout of incontinence. The SEAT3 in this study which had a cotton, non-incontinent cover had the best results from a thermophysiological standpoint.

In summary, we observed that the newly designed cover and cushion improved thermoregulatory responses during Neutral conditions, but not during Hot conditions. However, the incontinent covers, both standard and our new option, negated any benefits of the new cushion design. A hot environment negated any benefits from cushion design. These data suggest that seat cover is more important than seat cushion in terms of the physiological response during typical ambient room conditions.

Author contributions

BF and AR conceived the idea. GJH, AR, SSC, PK, BF designed the experiments. GJH and MMM completed data collection. GJH reduced and analysed the data. GJH and BF interpreted the data. GJH drafted the manuscript. MMM, AR, SSC, PK, and BF edited the manuscript critically for intellectual content. All authors approved the final version.

Disclosures

AR is the Co-Owner of Niagara Prosthetics & Orthotics Corporation. All other authors have no disclosures.

Conflicts of interest

The authors have no financial or other sources of conflict of interest relating to our submission of this manuscript.
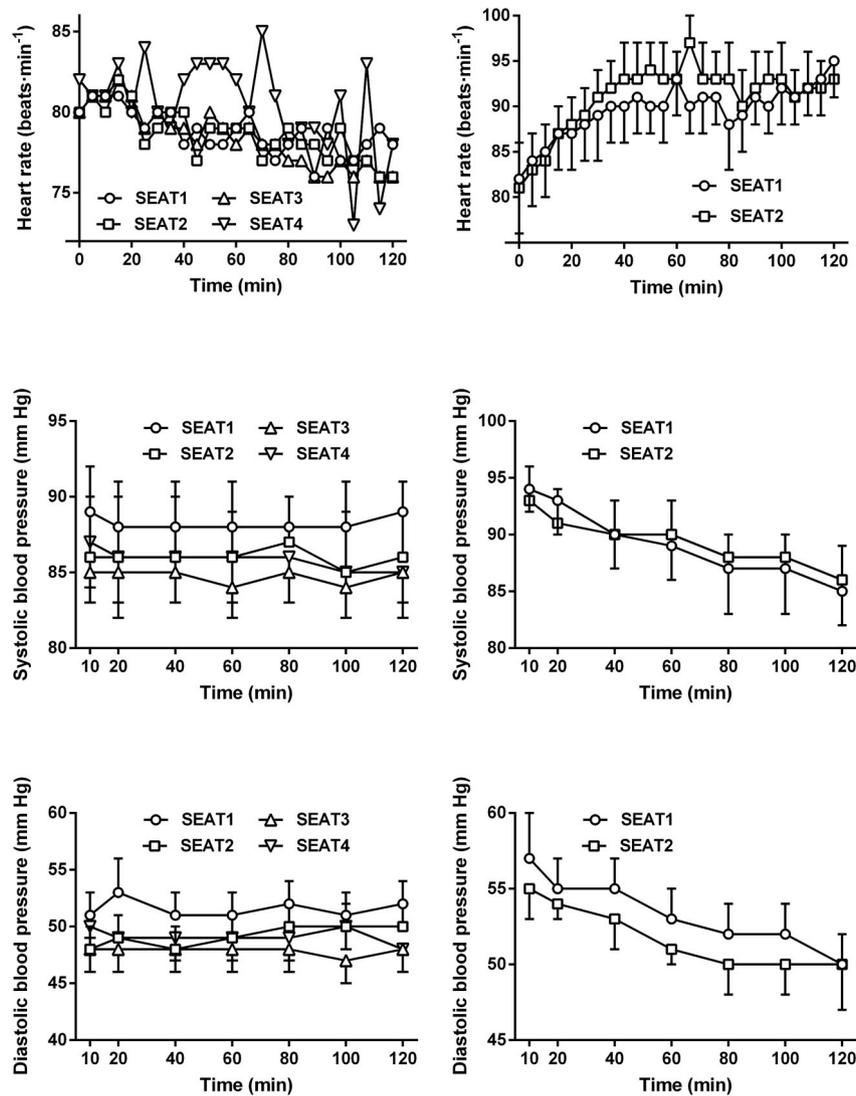
Fig. 7. Heart rate (A and B), systolic blood pressure (C and D), and diastolic blood pressure (E and F) for the Neutral and Hot conditions. There were no differences among the seating types for any of the measures. Error bars are omitted from panel A for clarity.

Table 4
Perceptual measurements.

TIME (min)	10	20	40	60	80	100	120
	Neutral						
Thermal Comfort							
SEAT1	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0
SEAT2	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0
SEAT3	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0
SEAT4	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0	1 ± 0
Thermal Sensation							
SEAT1	4 ± 0	4 ± 0	4 ± 1	4 ± 1	4 ± 0	4 ± 1	4 ± 1
SEAT2	3 ± 1	4 ± 0	4 ± 1	4 ± 0	4 ± 1	4 ± 0	4 ± 1
SEAT3	4 ± 0	4 ± 0	4 ± 0	4 ± 1	4 ± 0	4 ± 0	4 ± 0
SEAT4	4 ± 0	4 ± 0	4 ± 0	4 ± 0	4 ± 1	4 ± 1	4 ± 1
	Hot						
Thermal Comfort							
SEAT1	2 ± 1	2 ± 1	2 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
SEAT2	2 ± 1	2 ± 1	2 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Thermal Sensation							
SEAT1	6 ± 1	6 ± 1	6 ± 1	6 ± 1	7 ± 1	6 ± 1	7 ± 1
SEAT2	6 ± 1	6 ± 1	6 ± 1	6 ± 1	6 ± 1	6 ± 1	7 ± 1

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