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Skin Temperature Responses in a Hot Environment among Wheelchair Rugby and Basketball Players with Spinal Cord Injury

Nami Shida*, Yorimitsu Furukawa and Osamu Nitta

Division of Physical Therapy, Faculty of Health Sciences, Tokyo Metropolitan University, Japan

***Corresponding author:** Nami Shida, Division of Physical Therapy, Faculty of Health Sciences, Tokyo Metropolitan University, Japan, Tel: +81-3-3819-1211; Fax: +81-3-3819-7154; E-mail: shida@tmu.ac.jp

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Abstract

Objective: Individuals with spinal cord injury (SCI) have decreased vasomotor control and perspiration ability corresponding to the level of spinal damage. This study compared body surface temperatures between wheelchair rugby players with cervical SCI (CSCI) and wheelchair basketball players with thoracolumbar SCI (TSCI).

Methods: This is an observational study, including 10 male athletes with CSCI (mean age, 26.2 years) and 10 male athletes with TSCI (mean age, 29.7 years). The participants practiced wheelchair rugby and wheelchair basketball as per the format of a traditional game in a hot indoor environment. Body surface temperatures were measured before and after practice by thermography. Heart rate (HR) and maximum temperatures at measured sites (forehead, upper extremities, and lower extremities) were assessed.

Results: Body surface temperatures showed a significant correlation between pre- and post-exercise and between groups (CSCI and TSCI) [P=0.003], indicating that temperature changes were different between the groups. The temperature before exercise was higher in the TSCI group than in the CSCI group [P=0.033]. The temperature after exercise was higher in the CSCI group than in the TSCI group; however, no significant difference was found [P=0.117]. HR at rest and maximum HR were different between the groups (P<0.001). Both HRs were significantly higher in the TSCI group than in the CSCI group (At rest: P=0.020; Maximum: P<0.001).

Conclusions: We observed that the increase in body surface temperature because of exercise was higher in the CSCI group than in the TSCI group. There was no difference between the groups in terms of temperature on the forehead, where perspiration can occur. Cooling during the game was unable to prevent temperature increase. However, a limitation of the study is that exercise load was not measured, and cooling methods and amounts were not quantified.

Keywords: Cervical spinal cord injury; Thoracolumbar spinal cord injury; Perspiration; Heart rate; Core temperature; Disabilities; Skin temperature; Hot environment

Introduction

One of the challenges of rehabilitation in individuals with disabilities who have returned to their normal daily life is the maintenance and promotion of health. To maintain and improve muscle strength and prevent lifestyle-related diseases to facilitate living an independent life, it is important to develop an exercise habit. However, individuals with disabilities do not have sufficient opportunities for routine exercise. In Japan, exercise environments conducive to individuals with disabilities are scarce. There is a lack of information regarding the effectiveness and risk of exercise and inadequate support systems for individuals with disabilities. Currently, the awareness of sports for individuals with disabilities is increasing with the 2020 Tokyo Paralympics approaching. Alternatively, as the exercise environment for para-athletes is still limited, there are limited opportunities for individuals with disabilities in the community to enjoy sports.

Preparing athletes for the Olympics under conditions of high air temperatures and high humidity has become a concern. For example, in 2004 in Athens, the temperature was 30°C-38°C, and the relative humidity was 40%-48% [1]; in 2008 in Beijing, it was 20°C-30°C with 63%-90% humidity [2]; and in 2016 in Rio de Janeiro, it was 19°C-29°C with 70% humidity [3]. As summer in Tokyo is hot and humid, it can be predicted that athletes participating in the Tokyo Paralympics will also be affected by the climate. Many individuals with spinal cord injuries (SCIs) suffer dysfunction of their thermoregulatory system due to sympathetic regulatory insufficiency, including sweating, the vasomotor system, and thermogenesis starting below the level of their spinal damage [4]. The core temperature of individuals with cervical spinal cord injuries (CSCIs) is especially susceptible to the effects of ambient temperature because the paralysis caused by CSCIs extends over almost the entire body [5-9]. Several studies have examined the thermoregulatory function in individuals with SCIs during exercise. A study with a relatively low exercise load was conducted in an air-conditioned room, and it was found that the core temperature of individuals with CSCIs increased by approximately 1°C during exercise in a hot environment. The core temperature recovered more slowly after exercise in these individuals than in healthy individuals or those with lower SCIs [10,11]. While some studies have used an arm crank for exercise load [12,13], there is a difference in thermoregulation between upper extremity cranking and wheelchair exercises. This raises a question whether the results can be generalized to other sports

[14]. Results of a study recommended that future studies should focus on metabolic rate, sweating reaction, exercise condition, and sport-specific exercise protocols [15].

Reports of field studies that compared individuals with and without SCIs who participated in sports for disabled individuals, specifically wheelchair rugby [16] and wheelchair tennis [17], have indicated that those with SCIs experience an elevation in skin temperature and core temperature in hot environments compared with those without SCIs. Many previous studies used sensors such as loggers to measure skin temperature, with a few studies using thermography. The importance of infrared thermography in evaluating skin temperature has been increasingly recognized in clinical settings. Recently, infrared thermography has been used more frequently in sports and exercise medicine [18].

The current study was a field study on wheelchair sports with hot environmental conditions. In this study, a non-invasive thermography system was used to measure body temperature in athletes.

Regarding temperature acclimation and cooling strategies, a previous study of healthy individuals has shown that exercise training under hot atmospheric conditions is the most effective method to enhance temperature acclimation [19].

In rehabilitation, individuals with CSCIs use behavioral thermoregulation to assist heat radiation by spraying mist on the body surface to compensate for thermoregulatory dysfunction. Gradual environmental adaptation also promotes a better response capacity. In athletic games, various cooling strategies are used to assist heat dissipation and counteract heat retention and sweating disorders. Strategies include using an atomizer, a portable fan, and applying cold packs to the body surface.

For individuals with SCIs, exercising in summer results in a high body temperature (rising as high as ≥ 40°C) and increases the risk of hyperthermia [20]. An elevation of the core temperature leads to a decrease in exercise performance [21]. One method to suppress elevation of the core temperature is wearing a cooling jacket. This has been tested [13,22-24], but it has not yet been put into practice. Alternatively, it was reported that heart rate (HR) significantly increased while wearing a cooling vest [23]. Griggs et al. indicated that the effectiveness of cooling strategies is a fundamental issue that has not been sufficiently addressed, including cooling methods, timing, duration, and parts of the body to be cooled for athletes with SCIs in a game environment [3]. Controlling body temperature is a critical factor in enabling athletes to perform their best in a sport. It is important to conduct studies using highly trained athletes with SCI; this leads to improvement in overall performance using cooling strategies under conditions of real athletic games. Based on these concepts, the current study was conducted with highly trained elite athletes with SCI, focusing on the effects of intense training on the body and the effects of existing cooling strategies.

This study aimed to compare the skin temperature reactions between the athletes with CSCIs and thoracolumbar spinal cord injuries (TCSIs) participating in wheelchair rugby and wheelchair basketball.

Methods

Participants

The subjects of this study were elite male wheelchair rugby and wheelchair basketball athletes. The participants were 10 males with complete CSCIs and 10 males with TSCIs with a mean age [standard deviation (SD)] of 26.2 (4.0) years and 29.7 (5.8) years, respectively (Table 1).

	CSCIs	TSCIs	P value
Age (years)	26.2 ± 4.0	29.7 ± 5.8	0.135
Height (cm)	177.2 ± 4.2	172.9 ± 10.8	0.254
Body mass (kg)	66.0 ± 7.3	67.6 ± 16.2	0.779
Time since injury (years)	7.2 ± 3.3	14.0 ± 11.0	0.089
Level of Injury	C4-8	TH2-L3	
Sports experience (years)	4.1 ± 3.0	7.0 ± 3.1	0.048

Table 1: Physical attributes and participant characteristics of the two groups: wheelchair rugby players with cervical spinal cord injuries (CSCIs) and wheelchair basketball players with thoracolumbar spinal cord injuries (TSCIs).

Prior to participating in the study, the participants provided informed consent. This study was approved by the Ethics Committee of the Tokyo Metropolitan University Arakawa Campus (approval number: 16018). All procedures were conducted in accordance with the guidelines of the Declaration of Helsinki.

Study design

The measurements of body temperature and HR were conducted at a training camp for each sport. The CSCI group was measured first, and the TSCI group was measured 1 week later. The measurements were conducted in a gymnasium without air conditioning, and the atmospheric temperature and humidity in the gymnasium were continuously recorded. The sports performed during the study were wheelchair rugby (CSCI group) and wheelchair basketball (TSCI group). The measurements were recorded over 2 hours from warming up to practice in the form of a game. Prior to measurement, participants avoided drinking alcohol, smoking, eating, applying topicals (lotions, ointments), bathing or showering, sunbathing, and other activities that can affect skin temperature (such as massage and ultrasound).

Participants wore athletic shirts and shorts and were permitted to freely drink water and use cooling strategies (spraying, icing, air coolers, and electric fans) during exercise. The body temperature was measured after exercise and at least 10 min after the last cooling activity. The focus of the study was to reproduce the experience and conditions encountered during a real game.

Body surface temperature

The body surface temperature was measured using an InfReC R300 infrared thermographic camera (Nippon Avionics Co., Ltd., Tokyo, Japan). Participants were acclimatized to the measuring environment for 1 h before the measurement. Thermographic imaging was performed for the before-exercise measurement after a 30-min rest in a seated position in an athletic wheelchair.

The camera was turned on 1 h before commencing measurements and was set perpendicular to the area of interest. The body surface temperature (°C) was measured by taking a frontal view image at 3 m from each participant, with emissivity of 0.98%. Images were taken before and immediately after exercise in a seated position in an athletic wheelchair with bilateral shoulder abduction at 90°. Infrared thermography was completed using the guidelines of the Thermographic Imaging in Sports and Exercise Medicine checklist [25]. The InfReC Analyzer software (Nippon Avionics Co., Ltd., Tokyo, Japan) was used to analyze the thermal images, and temperatures were calculated for the highest point on the body surface and the highest specifically indicated points on the body: the forehead, the upper arm (the distal half of the forearm and the proximal half of the upper arm), and the lower leg.

Heart rate

The heart rate (HR) was measured using the Polar Team Pro heart rate sensor (Polar Electro Japan, Tokyo, Japan), which was worn on the chest by each participant after completing preparation. HR was continuously recorded every second starting immediately after wearing the sensor. HR [beats per minute (bpm)] was measured from the start of a 30-min rest period in a seated position in an athletic wheelchair to the completion of measurement of body surface temperature after training. From the measurements taken at rest, the measurement that was stable for 1 min was used as the HR at rest, and from the measurements taken during exercise, the highest measurement was used as the maximum HR. The mean HR during exercise was also calculated.

Statistical analysis

Data were represented as mean (SD). The normal distribution was tested using the Shapiro-Wilk test. A two-way analysis of variance (ANOVA) was performed with the body surface temperature as a dependent variable, CSCI and TCSI groups as unpaired variables, and the time before and after exercises as paired variables. A test of simple main effects was conducted if an interaction at the primary analysis was significant, and a test of main effects was confirmed if the interaction was not significant.

A two-way ANOVA was also performed with HR as a dependent variable, CSCI and TCSI groups as unpaired variables, and the time at resting and maximum HR as paired variables. A main effect was tested if an interaction was not significant. The effect size (ES) was calculated using G*Power software (Heinrich Heine University, Dusseldorf, Germany). Statistical analysis was conducted using SPSS ver. 22 (IBM Japan, Tokyo, Japan), and the significance level was set at 5%.

Results

In the measuring environment, the mean atmospheric temperature (SD) and the mean humidity (SD) were 28.3°C (0.3) and 70.4% (0.3) in the CSCI group and 29.4°C (0.3) and 65.4% (5.5) in the TSCI group, respectively.

Body surface temperature

In both groups, the highest points for body surface temperature measurements were the area from the face to the neck and the upper extremities. A significant interaction was observed for the maximum temperature between groups and between measurements taken before and after exercise (ES=0.79, P=0.003). The body surface temperature was significantly higher after exercise than before exercise in both groups (CSCI: ES=0.88, P<0.001, TSCI: ES=0.61, P=0.048). The body surface temperature before exercise in the TSCI group was significantly higher compared with that in the CSCI group (ES=0.56, P=0.033); however, the temperature after exercise did not differ between the groups (ES=0. 36, P=0.117) (Table 2).

	Pre [°C]	Post [°C]	ES	P (group)	P (time)	P (interaction)
CSCIs	35.7 (0.6)	37.2 (0.8)	0.79	0.932	<0.001	0.003
TSCIs	36.2 (0.3)	36.6 (0.7)				

Table 2: Pre-training and post-training P values and effect size (ES) at maximum skin temperature significant difference between groups at baseline and post-training, P<0.05 (CSCIs: Cervical spinal cord injuries; TSCIs: Thoracolumbar spinal cord injuries).

The interaction between the groups before and after exercise was confirmed for each site. The upper limbs and lower limbs showed interaction (upper extremity: ES=0.73, P=0.006; lower extremity: ES=0.56, P=0.028), but no interaction was observed for the forehead (ES=0.16, P=0.493). Time showed a main effect on the forehead temperature, which was elevated after exercise; however, there was no difference between the groups. A simple main effect on the upper and lower extremities showed that the temperature of both the upper and lower extremities was significantly higher in the TSCI group than in the CSCI group before exercise (upper extremity: ES=0.50, P=0.024; lower extremity: ES=0.71, P<0.001); however, no difference was found after exercise (upper extremity: ES=0.22, P=0.355; lower extremity: ES=0.20, P=0.401).

	CSCIs		TSCIs					
	Pre [°C]	Post [°C]	Pre [°C]	Post [°C]	ES	P (group)	P (time)	P (interaction)
Forehead	35.4 (0.4)	36.3 (1.1)	35.8 (0.7)	36.4 (0.9)	0.16	0.416	0.003	0.493

Upper limbs	34.1 (1.0)	36.3 (1.2)	35.2 (1.1)	35.9 (1.0)	0.73	0.393	<0.001	0.006
Lower limbs	31.4 (1.1)	33.8 (0.7)	33.5 (1.1)	34.4 (2.0)	0.56	0.015	<0.001	0.028

Table 3: Pre-training and post-training P values and effect size (ES) at the temperatures of the highest points within each specified range: the forehead, upper limbs, and lower limbs (Significant difference between groups at baseline and post-training, P<0.05. CSCIs: Cervical spinal cord injuries; TSCIs: Thoracolumbar spinal cord injuries).

The CSCI group showed a significant increase in the temperature of the upper and lower extremities after exercise (upper extremity: ES=0.17, P=0.001; lower extremity: ES=0.87, P=0.025). Alternatively, the TSCI group showed an increase in temperature after exercise only for the upper extremities (ES=0.67, P<0.001) with no difference in temperature after exercise for the lower extremities (ES=0.54, P=0.088) (Table 3).

Heart rate

The mean HR (SD) during exercise was 110.6 (24.5) bpm in the CSCI group and 132.1 (27.6) bpm in the TSCI group. An interaction was observed among HR at rest, maximum HR, and HR between groups (ES=1.18, P<0.001). It indicated that changes in HR at rest and maximum HR were different between the groups (Table 4).

	At rest [bpm]	Maximum [bpm]	ES	P (group)	P (time)	P (interaction)
CSCI	76.8 (7.5)	141.5 (16.5)	1.18	<0.001	<0.001	<0.001
TSCI	87.1 (10.3)	180.6 (9.3)				

Table 4: Pre-training and post-training P values and effect size (ES) at maximum heart rate (Significant difference between groups at baseline and post-training, P<0.05. CSCIs: Cervical spinal cord injuries; TSCIs: Thoracolumbar spinal cord injuries)

In both groups, HR increased during exercise compared with HR at rest (CSCI: ES=0.98, P< 0.001; TSCI: ES=1.00, P<0.001).

HR at rest and maximum HR were significantly higher in the CSCI group than in the TSCI group (At rest: ES=0.52, P=0.020; Maximum: ES=0.82, P<0.001).

Discussion

We measured changes in the body surface temperature of athletes with CSCI and those with TSCI while playing sports under hot atmospheric conditions. Both HR at rest and maximum HR were lower in the CSCI group than in the TSCI group. In athletes with CSCI, cardiac sympathetic nerve (T1-4) that adjusts the heart rate is cut off, and depends on the suppression of the competing vagus nerve activity. Furthermore, there are many reports stating that it is adjusted by drop of parasympathetic nerve activity and catecholamine in blood, and that the maximum heart rate is between 110130. This is likely attributable to the decrease in sympathetic innervation to the heart in individuals with CSCI [26]. Based on the mean HR and maximum HR during exercise, the intensity of the exercise was estimated to be high; however, the quantity of motion, such as speed and distance, was not measured.

The body surface temperature after exercise was higher in the CSCI group than in the TSCI group. These results are similar to those reported in a previous study that describes greater increases in body temperature under hot conditions in individuals with CSCI than in individuals with TSCI or in healthy individuals [13,15,16]. The maximum temperatures before exercises were higher in the TSCI group than in the CSCI group. This appears to be due to the difference in the resting metabolic rates of the CSCI and TSCI groups, owing to the presence of greater residual muscles in the latter group. This is also attributable to higher temperatures of the upper and lower extremities before exercise in the TSCI group. Furthermore, the CSCI group showed higher body surface temperatures than those in the TSCI group after exercises. The living body increases blood flow to the skin in order to adjust body temperature through exercise, and perspiration is triggered. When the spinal cord is damaged, these are obstructed because the sympathetic nerve activity below the damaged area is lost. Although the sympathetic nerve run along the spinal cord, parasympathetic nerve takes a different route. Thus, when the sympathetic nerve is damaged, the parasympathetic nerve remains intact and becomes predominant. Moreover, for athletes above T5, not only is the paralyzed area is wide, but the sympathetic nerve activity at the ends are cut off from upper central. The CSCI group was unable to achieve sufficient heat dissipation due to impairments in the regulation of cutaneous blood flow and regulation of perspiration associated with autonomic dysfunction. Therefore, athletes in the CSCI group were likely unable to reduce their elevated body temperatures during exercise, unlike those in the TSCI group.

This study showed that the body surface temperature of the individuals in the CSCI group increased to 37.2°C (0.8°C) after exercise, and the temperatures of their upper and lower extremities were also elevated. In this study, the skin surface temperatures were measured, but the core temperature was not measured. However, the skin temperature is positively correlated with the core temperature [27], and Mikami et al. noted a significant positive correlation between oral temperature and skin temperature of forehead and dorsal hand in three of four individuals with CSCI. This indicates that the oral temperature of a person with CSCI can be estimated from the skin temperature on the forehead and dorsal hand, although there are individual differences [28]. Furthermore, Griggs et al. reported that the core temperature of players with a cervical spinal cord injury (n=10) and non-spinal related physical impairment (n=7) was higher than the skin temperature [16]. Based on these, it was inferred that the increase in body surface temperature in the individuals of the current study also appeared to be accompanied by an increase in core temperature.

In our study, cooling was allowed while playing sports without any restrictions on factors such as duration and timing, and cooling actions (spraying, icing, air coolers, and portable electric fans) and drinking water were available for the athletes, as in normal circumstances. A previous study examining the effects of spraying water as a cooling activity showed that the core temperature increased from 1.3°C to 1.8°C during exercise, irrespective of the area and frequency of spraying water. The report concluded that spraying water did not prevent heat retention [27]. Our study also suggests that the cooling methods routinely used by athletes may not sufficiently control the increase in body temperature while playing sports. This indicates that the risk of hyperthermia is high, even with the current measures employed against heat retention. As a result, performance may be negatively affected by high body temperature while playing sports. Quantitative assessments of cooling, such as duration, methods, or other parameters, were not conducted, and therefore, further examination in this area is required.

When analyzing temperature as per measurement site, the temperature of the forehead did not show any difference between the groups. Mikami et al. stated that the skin temperature of the forehead of individuals with CSCI was susceptible to change in response to ambient temperature [28]. Hirata et al. reported that the skin vasodilation threshold of the forehead was lower than that in other areas, making blood flow in the skin of the forehead greater than that in other areas regardless of the intensity of exercise [29]. Occasional case reports have also described excessive perspiration on the face in individuals with CSCI [30,31]. These reports indicate the possibility of a compensatory mechanism that involves changing the temperature of the non-paralyzed forehead to compensate for difficulty in regulating dry heat loss; this can be done by changing the temperatures of the peripheral regions of the upper and lower extremities due to skin vasomotor disturbance in individuals with CSCI. In our study, because participants in both groups were able to perspire on the forehead, this may explain why the forehead temperature did not show differences between the groups. Moreover, in addition to drinking water, the participants in this study were permitted to freely cool themselves using their usual methods. Cooling the large blood vessels, such as the axillary and carotid arteries, is considered an effective measure to lower body temperature, but cooling during and between sports activities using sprays or air coolers often targets the face and neck where the skin is exposed. This may influence forehead temperature, reducing the gap between the groups.

The temperature of the upper extremities was significantly lower in the CSCI group than in the TSCI group before exercise. After exercise, although it was higher in CSCI group than in the TSCI group, there was no significant difference between the two groups. In wheelchair sports, athletes repeatedly use the muscles of their upper extremities, mainly for maneuvering their wheelchairs. This use of agonist muscles of the upper extremities causes the muscles themselves to produce heat, thereby increasing the body temperature. Several factors may have contributed to the lack of a significant difference between the groups after exercise. Athletes in the TSCI group were able to disperse muscle actions because they could use some muscles in the lower extremities and trunk as well as those in the upper extremities. They were able to decrease body temperature more in comparison to athletes in the CSCI group because those in the TSCI group were able to utilize the cutaneous blood flow regulation and regulate perspiration.

Regarding skin temperature of the lower extremities, both groups show lower temperatures in the paralyzed lower extremities compared with upper extremities. This is likely due to lack of heat production by the muscles in the lower extremities because these muscles were not employed by individuals in either group. In the CSCI group, the lower extremity temperature significantly increased after exercise. Normally, perspiration markedly promotes heat dissipation; therefore, skin temperature decreases. In a paralyzed area, perspiration function is deteriorated [32,33], and the skin dries in areas where no perspiration is produced. This causes the skin temperature to increase in response to the atmospheric temperature [34]. Nevertheless, individuals in both groups in our study had paralysis in the lower extremities. In previous studies, researchers did not observe any differences in skin temperature on the chest and upper arms by the level of spinal cord injury. There was a tendency for the skin temperature to increase in individuals with upper level SCIs as the site of measurement moved down from the thigh to the calf and the lower leg [34]. Other researchers reported that the skin temperature of lower extremities increased because of an increase in heat storage in the upper extremities during a long-term (90 mins) upper extremity exercise [15,35]. The results of our study support these findings. The core temperatures of individuals with CSCI are prone to fluctuate in response to ambient temperature [5-9]. In addition to the effect from ambient temperature, the blood that accumulated heat in non-paralyzed muscles circulated throughout the body in the CSCI group, increasing the body surface temperature of the lower extremities. In contrast, the paralyzed area that is incapable of heat production from muscles is susceptible to hypothermia, leading to hypothermia in the whole body under cold conditions. For healthy individuals, exercise is an effective method to strengthen local and whole-body cold resistance [36]. Similarly, in individuals with SCI, upper extremity exercise impacts the paralyzed areas, and it can be anticipated to promote favorable effects on the entire body, including preventing hypothermia and improving systemic circulation.

This study had several limitations, i.e., the amount of exercise load, and the methods and amount of cooling were not quantified. However, this study was characterized by targeting elite athletes with complete SCI, was a practical field study, and used thermographic imaging.

This study found that athletes with SCI experience increased body surface temperatures when engaging in exercise in hot environments and that the increase is greater for athletes with CSCI than those with TSCI. Loss of heat dissipation ability as a result of SCI causes excessive core temperature increase, which decreases the individual's ability to exercise and increases the risk of heat-related illnesses. To prevent body temperature increases, a variety of external and internal cooling strategies have been proposed by previous research [37,38] and are currently utilized. However, since athletes with SCI have autonomic neuropathy as well as disorders of the digestive and excretory systems, some of the strategies have been empirically avoided and some others are impractical or insufficiently effective to be applied during sporting events. The present observational study involving fieldwork revealed that the currently used cooling strategies are insufficient. Thus, more practical and effective cooling strategies for overheating during sporting events that are based on the experiences of athletes with SCIs and new knowledge are necessary.

To improve competitiveness and performance and promote sports as a lifestyle to maintain and improve health, it is important to understand the physiological characteristics of athletes with disabilities and practice sports based on this understanding.

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Conflict of Interest

There are no conflicts of interest to declare.

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