Journal of Ergonomics

Ueda and Inoue, J Ergonomics 2013, 3:3
DOI: 10.4172/2165-7556.1000121

Research Article | Open Access

Improved Procedure for Estimating Time-dependent Changes in Local Sweat Rates by Measuring Local Sweat Volumes

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Abstract

Sweat distribution over 21 body sites in 8 young males was described by determining the local sweat volume (LSR_{ap}), measured using absorbent pads throughout 3 different bicycle exercises performed at 35, 50, and 60% VO_2max for 40 min, at 30°C and 50% relative humidity. The local upper back sweat rate was concurrently measured by the ventilated capsule method (LSR_{vc}) in parallel with the absorbent method. The LSR_{ap} at the upper back correlated strongly with mean LSR_{vc} at the position immediately above the absorbent pad ($p<0.05$). There were significant differences in LSR_{ap} among the 21 body sites within each exercise intensity ($p<0.05$). Regional comparisons showed a greater LSR_{ap} at the chest and back and lower LSR_{ap} at the flank, thighs, and legs. Moreover, LSR_{ap} was distributed symmetrically and was greater in the middle compared to the adjoining lateral sites. LSR_{vc} data reanalysis of our previous studies on prepubertal boys, men, and women across a range of ages revealed that during passive and/or active heating, the LSR_{vc} were arranged in order of lower limbs<upper limbs and trunk<forehead. Conversely, the minute percentage sweat rate (%LSR_{vc}), which was calculated by dividing LSR_{vc} by the sum of LSR_{vc} throughout the experiment, was not affected by body site. Thus, as the time-dependent changes in LSR at anybody site could be used as a substitute for that at any other body site, time-dependent changes in LSR_{ap} at various sites could be estimated by multiplying LSR_{ap} by %LSR_{vc} measured at any single site. In conclusion, an overview of local sweat distribution during the course of an experiment can be obtained by using absorbent pads that are easily fixed onto the skin, even under clothes, and time-dependent changes in LSR_{ap} can be estimated from LSR_{vc} at any single body site.

Keywords: Sweating; Regional difference; Exercise; Absorbent pad

Introduction

The evaporation of sweat plays an important role in body heat loss, which is required for the maintenance of body core temperature during passive and/or active heating. Previous studies of regional sweat rates found that the local sweat rate (LSR) clearly varies among the different body sites [1-6], and that LSR on the forehead and torso was greater than that of the limbs [1-4]. Some studies have focused on the differences in sweat regulation depending on maturation and aging [7-11], sex [12,13], fitness [8,14,15], and heat acclimation [8,16] to elucidate the mechanism underlying thermoregulation.

LSR is measured by using a ventilated capsule, and is estimated from the difference in vapor content between the influx and efflux air moving through the capsule at a known flow rate [3-7,10-13,15,16]. A few small capsules with less than 10 cm^2 in the project areas were generally used, with one capsule per one body part in the majority of previous studies. LSR is typically measured for a very small area of body skin when using the ventilated capsule method, and continuous measurements allow easy detection of the sweat response to changes in body temperature, which is simultaneously measured. Although the ventilated capsule method is suitable for physiological investigations, LSR data obtained from an extensive area of skin is required for developing a model of human thermoregulation, sweating thermal manikins, or designing protective clothing, sportswear, and outdoor clothing with transpiration efficiency. In addition to the small area targeted for measurement, the ventilated capsule method has a disadvantage when studying about body areas covered by clothing, because it is difficult to affix the apparatus, which consists of a thick capsule with a couple of air tubes, to the skin under the clothes.

LSR can also be estimated using absorbent materials. It was initially estimated from the difference in the mass of a filter paper that absorbs sweat directly from the skin surface in a capsule fixed onto the skin [2,8,9,17]. Recently, the absorbent technique was further developed by using patches of absorbent material placed over the skin for a short period of time [18-20]. It has been verified that LSR measured with absorbent patches is in very good agreement with that obtained by using ventilated capsules [18]. This absorbent technique has been used to estimate LSR across larger skin areas in runners and football players [19,20]. Moreover, this method was adopted for body mapping of sweating patterns [21,22]. Although the results provided valuable information for the design of clothes, these maps still offered a snapshot of LSR during exercise.

However, the absorbent technique has also been applied to determine LSR over an extended period of time [23,24]. These studies showed that sweat could be collected from the skin surface over a 1-2 hour period while performing light or moderate intensity exercises using a hospital-use pad with both highly absorbent materials and a surface sheet, which minimalize hidromeiosis. This method opens the possibility for measuring LSR under the clothes during experiments or in field tests; however, it does not provide information regarding the time-dependence of changes in the sweat rate.

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Received August 07, 2013; **Accepted** October 02, 2013; **Published** October 10, 2013

Citation: Ueda H, Inoue Y (2013) Improved Procedure for Estimating Time-dependent Changes in Local Sweat Rates by Measuring Local Sweat Volumes. J Ergonomics 3: 121. doi:10.4172/2165-7556.1000121

The aim of this study was to describe the distribution of the sweat volume during moderate intensity exercises by using absorbent pads and to discuss a procedure for estimating time-dependent changes in sweat rates based on the local sweat volumes, which are estimated by the LSR measurement for an exposed area of the skin, using the capsule method.

Methods

Study 1

Subjects: Eight men, who were short-distance runners and jumpers belonging to University's track team, volunteered as subjects. All experiments were conducted during September when the subjects had acclimated to the hot environment. All experimental procedures were fully explained to the participants, who signed an informed consent form after completing a health screening questionnaire. Their physical characteristics were as follows: age, 20 ± 0.4 y; height, 168.8 ± 1.9 cm; mass, 58.81 ± 1.12 kg; AD/mass, 276.6 ± 2.4 cm^2/kg; mean skinfold thickness at 6 sites (the infrascapular area, flank, posterior upper arm, anterior forearm, anterior thigh, and posterior leg), 7.9 ± 0.4 mm; and maximal oxygen uptake (VO_2max) estimated by performing submaximal exercise at 4 or 5 different intensities on a cycle ergometer, 48.7 ± 2.1 ml/kg/min. The experimental procedures were approved by Osaka International University Ethical Committee.

Preparation of the absorbent pads: LSR was determined by taping the absorbent pads directly to skin surface at 21 body sites, which were then maintained for the entire duration of the exercise. The absorbent pad used in this experiment consisted of an adhesive dressing with an absorbent pad (15 × 5.5 cm, OPSITE Post-OP, Smith & Nephew plc, London, UK); this consisted of a waterproof adhesive film, a highly absorbent pad, and a contact layer. This product, capable of water absorption of approximately 200 mg/cm^2 when placed briefly on the surface of a sponge dipped in saline solution, possessed satisfactory absorbency for sweat collection over a period of 1 hour during moderate exercises under standard conditions [23]. The elasticity and cohesive property of adhesive film ensured appropriate sealing of the area. Hence, once the film has been fixed to skin, it is unlikely to detach from the skin even while sweating. The film is waterproof, preventing the pad from absorbing the sweat that drops on it from other body sites. However, as the film is moisture vapor-permeable, another impermeable adhesive was placed over the pad during the trial to prevent transpiration of the absorbed sweat. The contact layer enables sweat to pass readily through to the absorbent pad, preventing the skin surface from becoming excessively wet. Prior to the experiments, the adhesive dressing was tailored to the specification for the precise measurement. To prevent the pad from absorbing the sweat from the surrounding area, urethane sponge tapes with 2 × 2 mm cross-sectional dimensions (i.e., of the same thickness as the pad), were affixed to all 4 sides of the pad as a barrier. Moreover, thin highly absorbent tapes, approximately 5-mm wide, were fixed on the extraposition in parallel with the urethane sponge tapes (Figure 1). The tailored pads were stored at 25°C and 50% relative humidity (RH) until required.

Protocol: For each participant, the experiment consisted of 3 randomized trials, viz., 35, 50, and 60% VO_2max bicycle exercises for 40 minutes, at a pedaling cadence of 50 rpm. All trials were conducted in a chamber controlled at 30°C and 50% RH. Each participant performed their experiments at the same time on separate days to minimize circadian variation. They were asked to refrain from consuming alcohol and to rest for a day prior to the trial. Additionally, they were instructed against excessive activity in the morning of the trial day, and to ingest no food or water for 2 hour prior to arrival at the laboratory and until the end of the trial. Participants were weighed on a platform scale (± 10 g accuracy) while wearing trunks, socks, and shoes, and then remained at rest on a stool in the chamber anteroom, which was maintained at a temperature of 25°C and 50% RH, for more than 30 minutes while instrumentation was attached.

The ventilated capsule (7.1 cm^2) was fixed to the upper section of the left scapula and the local sweat rate (LSR_{vc}) was measured during the exercise by using the ventilated capsule method [3-7,10-13,15,16] in parallel with the absorbent pad method. The tailored pads were placed on 21 body sites (on the right [R], left [L], and middle [M] section of the chest, abdomen, upper back, and lower back; L and M of the posterior upper arm; L of the anterior forearm, posterior and anterior of the thigh, and posterior and anterior of the leg; and both sides of the flank) within approximately 3 minutes before the trial. To prevent the transpiration of absorbed sweat through the adhesive film, an impermeable adhesive film, equal in size to the pad, was placed over the film after fixing the tailored pads to the skin.

Immediately upon completing attachment of the instrumentation, participants pedaled on a cycle ergometer for 40 minutes. Heart rate was measured before and throughout the trial at 5 minutes intervals. Rectal temperature (Tre) and skin temperature at 4 body sites (chest [T1], back [T2], forearm [T3], thigh [T4]) were measured every minute during the trial. Mean weighted skin temperature [Tsk] was calculated from the skin temperature at 4 sites by using a modification of the equation reported by *Roberts* et al. [25]:

$$Tsk=0.43\,([T1+T2]/2)+0.25\,T3+0.32\,T4$$

Mean body temperature [Tb] was calculated using the formula by Hardy and DuBois [26]:

$$Tb=0.8\,Tre+0.2\,Tsk$$

After the exercises, a part of the absorbent pad was pulled out from each of the tailored pads fixed on the skin. Each absorbent pad was quickly placed, separately, into an impermeable plastic Ziploc bag and weighed with the bag. By employing several assistants, these steps could be completed within approximately 3 minutes after the exercises. Participants were re-weighed directly after de-instrumentation. Each of the pads were dehydrated for more than 24 hour at 25°C and 50% RH,

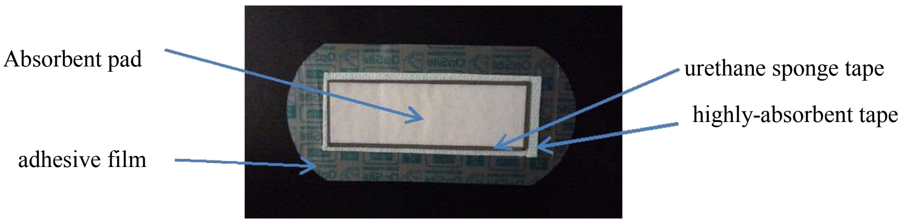

Figure 1: The absorbent pads used in this experiment (patched side).

and re-weighed with their bag. The local sweat volume was calculated based on the mass gain of the pad. The weight of electrolyte remaining behind was not considered in this study. Local sweat volumes at 21 body sites measured using the absorbent pads were converted into the LSR per unit of area per minute (LSR_{ap}) for the 3 exercise intensities, and the mean LSR during each of the exercises was calculated.

Study 2

The sweat production data gathered by 3 series of studies by our group [13,25-28] on prepubertal boys and men and women of all ages were comprehensively reanalyzed. In these studies, LSR_{vc} at 4 or 5 body sites were measured continuously by using the ventilated capsule method in the following test conditions: a leg immersion test [27,28] in which 13 young males, 14 older males, 12 young females, and 9 older females immersed their legs in a 42°C stirred water bath for 40 minutes in a chamber maintained at 30°C and 45% RH; a constant intensity exercise test [29,30] in which 6 prepubertal boys, 9 young males, and 5 older males performed 3 different cycling exercises at 35, 50, and 65% VO_2max for 30 minutes in a seated position at 28°C and 40% RH on separate days; and an incremental exercise test [13] in which 5 trained males, 8 untrained males, 10 trained females, and 9 untrained females performed a continuous graded cycling exercise in the semi-supine position at 35, 50, and 65% VO_2max for 20 minutes each without rest between intensity changes, at 30°C and 45% RH. The minute percentage sweat rate (%LSR_{vc}) was calculated by dividing the LSR_{vc} by the sum of the LSR_{vc} throughout the experiment according to the body site.

Statistics

Statistical analysis was performed using SPSS Ver.19 (IBM Corp. N.Y. USA). The differences in Tre, Tsk, Tb, HR, whole body sweat loss, and LSR_{ap} at each body site for the 3 exercise intensities were compared using one-way ANOVA for repeated measures. LSR_{vc} were compared using a two-way ANOVA for repeated measures, with time and exercise intensity as factors. The agreement between LSR_{ap} and LSR_{vc} at the upper back was examined by correlation analysis. A one-way ANOVA for repeated measures was also used to compare LSR_{ap} and LSR_{vc} at the upper back as well as the differences in LSR_{ap} among body sites, for each exercise intensity group. When a significant F-value was observed after LSR_{ap} comparison among the 21 body sites, Bonferroni's post hoc comparison was performed.

Data in Study 2 were analyzed using two-way ANOVA for repeated measures within the participant group for each of the 3 tests in order to examine the body site-based differences in LSR_{vc} and %LSR_{vc}. In addition, the coefficients of variation, which were derived from values at 4 or 5 body sites on a minute-by-minute basis, were calculated as an indicator of the degree of body regional differences in LSR_{vc} and %LSR_{vc}, and then their means were calculated every 10 minutes during the experimental period.

Results

Study 1

The mean values (SEM) of the absolute exercise intensities, the increment of Tb, Tre, Tsk, HR, and whole body sweat loss during the exercises are shown in Table 1. Baseline values for Tre, Tsk, and HR immediately before commencing exercise were not significantly different among the 3 exercise intensities. Tre increased gradually with time at 35%, 50%, and 60% VO_2max. Tsk increased up to 10-20 min after commencing exercise and then remained on the same level at 35 and 50% VO_2max, or continued increasing at 60% VO_2max. There were significant differences in the increase of Tre, Tsk, and Tb among the 3 exercise intensities ($p<0.05$). The degrees of increase in Tre, Tsk, and Tb during each exercise followed the order of the exercise intensities. HR increased shortly after commencing the exercise, and the final values were significantly different for the 3 exercise intensities ($p<0.05$). HR during the exercise period was ranked in the order of the exercise intensities. Whole body sweat loss, which was estimated from the weight lost during the exercise, increased significantly with the exercise intensity ($p<0.05$).

Figure 2 shows the time course of LSR_{vc} at the upper back, as measured using the ventilated capsule method. In each participant, sweating started at 3-9, 4-7, and 1-6 minutes after commencing exercise at 35%, 50%, and 60% VO_2max, respectively, and LSR_{vc} increased significantly with time ($p<0.05$). LSR_{vc} showed significant interactions with time and exercise intensity, aside from the main effects ($p<0.05$). LSR_{vc} values after the onset of sweating corresponded to the exercise intensities values. Local sweat volumes at the 21 body sites measured by absorbent pads were converted into LSR per unit of area per minute (LSR_{ap}) for the 3 exercise intensities to give the mean LSR during the exercise (Figure 3). There were significant differences in LSR_{ap} among the 3 exercise intensities within each body site ($p<0.05$). Although LSR_{ap} differences for 35% and 50% VO_2max or 50% and 60% VO_2max at some body sites were not significantly different, LSR_{ap} showed a significant increase from 35% to 60% VO_2max at all body sites following post hoc comparisons.

The agreement between the 2 measurement methods was examined. LSR_{ap} at the left upper lateral back was strongly correlated with LSR_{vc} at the position immediately above the absorbent pad that was measured using the ventilated capsule method ($r=0.838$, $p<0.01$; $n=24$). LSRap at the left and right upper lateral back were 0.55 (0.06) and 0.52 (0.05), 0.83 (0.10) and 0.85 (0.10), and 1.16 (0.10) and 1.11 (0.08) mg/cm^2/min at 35%, 50%, and 60% VO_2max, respectively. Mean LSR_{vc} during the exercise were 0.51 (0.06), 0.82 (0.10), and 1.15 (0.06) mg/cm^2/min for 35%, 50%, and 60% VO_2max, respectively. There were no significant differences among the mean LSR_{vc} and LSR_{ap} values at the right and left upper lateral back sites, for each exercise intensity group. These results

	35%VO_2max		50%VO_2max		60%VO_2max	
Exercise intensity (W)	60.3 (3.8)		88.8 (4.1)		108.9 (5.3)	
ΔTb (°C)	0.22 (0.05)		0.57 (0.06)		0.85 (0.08)	
	At the rest	**At the end**	**At the rest**	**At the end**	**At the rest**	**At the end**
Tre (°C)	37.04 (0.12)	37.28 (0.06)	37.18 (0.12)	37.85 (0.09)	37.11(0.11)	37.96 (0.11)
Tsk (°C)	34.40 (0.15)	34.49 (0.23)	34.47(0.09)	35.04 (0.20)	34.35 (0.14)	35.20 (0.15)
Heart rate (beat min^{-1})	68 (3)	105 (2)	74 (5)	135 (2)	77 (6)	156 (5)
Body sweat loss (g m^{-2}h^{-1})	298 (39)		424 (61)		583 (0.18)	

Table 1: Absolute exercise intensities, increment of mean body temperature (ΔTb), rectal temperature (Tre), mean skin temperature (Tsk), heart rate, and whole body sweat loss during exercise at 35%, 50%, and 60% VO_2max.

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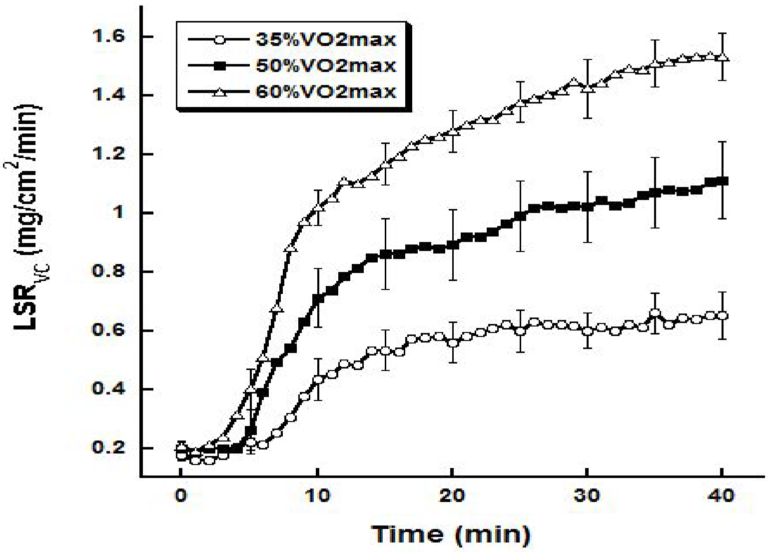

Figure 2: Local sweat rate (LSR_{vc}) at upper back measured by using the ventilated capsule method.

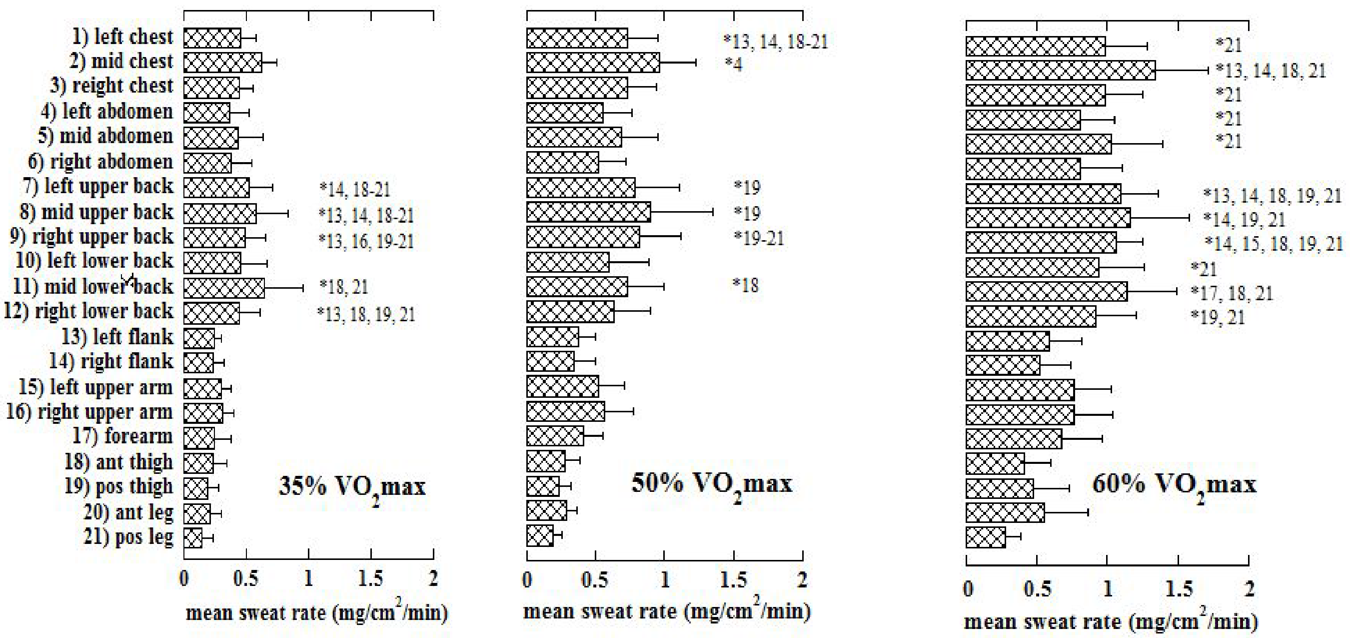

Figure 3: Regional sweat rate converted from sweat volume measured by the absorbent pads throughout the exercises. Values are mean and error bars indicate SEM. *p<0.05 significantly different from the numbered body site.

indicated that mean LSR measured by using the absorbent pad method correlated well with mean LSR measured by using the ventilated capsule method.

Large LSR_{ap} variations were observed between different body sites for each exercise intensity group, as shown in Figure 3. There were significant differences in LSR_{ap} among the 21 body sites within each exercise intensity group ($p<0.05$). Post hoc comparisons showed a relatively higher LSR_{ap} at the back compared to the flank, thigh, and legs at 35% VO_2max ($p<0.05$). Moreover, LSR_{ap} was higher at the chest and back than that at the flank, thigh, and legs at 50% and 60% VO_2max ($p<0.05$). With respect to upper body LSR_{ap}, values at the middle of the chest and upper back were greater than LSR_{ap} at the flank at 50% and 60% VO_2max ($p<0.05$). When the right-left differences in LSR_{ap} were investigated for different regions, no significant differences between lateral positions were noted at the chest, abdomen, upper and lower back, flank, and upper arm, for any exercise intensity.

Study 2

Figure 4 shows the changes in the 10-min averages of LSR_{vc} and $\%LSR_{vc}$ of a typical case in young male subjects in a leg immersion test. The LSR_{vc} increased over time ($p<0.05$) and displayed a large variation among the different body sites ($p<0.05$) in the 3 tests, regardless of age,

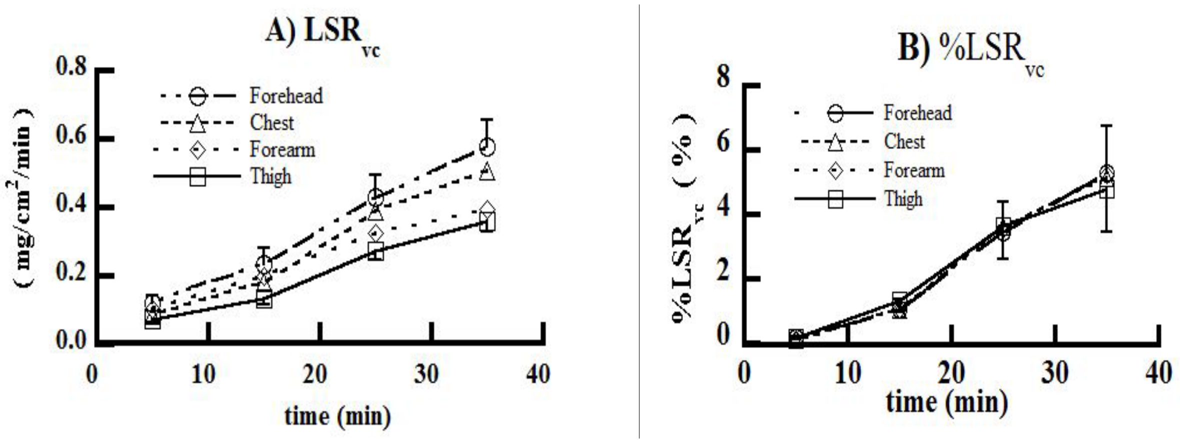

Figure 4: The changes of 10-min average for A) the mean local sweat rate (LSR_{vc}) and B) the minute percentage sweat rate ($\%LSR_{vc}$) calculated by dividing the LSR_{vc} by the sum of the LSR_{vc} throughout the experiment in young male subjects (n=13) in a leg immersion test.

sex, and training. LSR_{vc} showed significant interactions with time and body sites, aside from the main effects ($p<0.05$). Although the regional differences were observed to vary according to age, sex, and training, the LSR_{vc} values for any participant were arranged in the following order: lower limbs<upper limbs and trunk<forehead during the steady state sweating in later stages of the exercise. Conversely, $\%LSR_{vc}$, which was calculated by dividing the LSR_{vc} by the sum of the LSR_{vc} throughout the experiment, increased significantly over time in the same manner ($p<0.05$); however, $\%LSR_{vc}$ showed no significant main effect of the body site in most cases.

The mean onset time of sweating in all participants were 10.8 (± 0.7), 9.4 (± 0.3), and 11.4 (± 0.5) minutes after commencing exercise in the 3 tests, respectively. Hence, the body regional differences in LSR_{vc} and in $\%LSR_{vc}$ were compared in terms of their coefficients of variation after 10 minutes for each test. The coefficients of $\%LSR_{vc}$ were clearly smaller than those of LSR_{vc} within any individual case ($p<0.05$), with the exception of prepubertal boys at 35% VO_2max in a constant-intensity exercise test (Table 2).

Discussion

Measurement of LSR_{ap} by using the absorbent pad method is a portable and cost-effective approach, and it allows estimation of LSR_{ap} across a larger skin area compared to the ventilated capsule method. However, it fails to provide information on the time-dependent changes in the sweat rate. The aim of this study was to describe the distribution of LSR_{ap} by using the absorbent pads and to develop a procedure for estimating time-dependent changes in sweat rates from local sweat volumes measured by using absorbent pads. As the area of the absorbent pads used in this study was 82.5 cm^2, it allowed investigation of a sampling area much larger than that sampled by the conventional ventilated capsule method. Thus, the absorbent pad could provide information on a large surface area per sample. *Morris* et al. verified the agreement of the absorbent pad technique with the traditional ventilated capsule method only for brief sampling periods [18]. In contrast, in this study, the absorbent technique was applied to obtain an overview of local sweat distribution during the course of a 40-min exercise. The agreement of the 2 measurement methods could be demonstrated by the strong correlation between LSR_{ap} and LSR_{vc} at adjoining positions and the comparable values of LSR_{ap} and LSR_{vc} within each exercise intensity group in this study. LSR_{ap} at the 21 body sites increased significantly with an increase in the exercise intensity. The rates of increase in LSR_{ap} at the 21 body sites at 50% and 60% from 35% VO_2max fell within the range of 112-183% and 174-280%, respectively. Although the large increase rates were seen at flank and limbs at 60% VO_2max, they fell within an acceptable range when considering that the increase rate of sweat loss across the whole body at 50% and at 60% from 35% VO_2max were 143% and 196%, respectively. The increase rates in LSRap at the flank, forearm, thigh, and leg were relatively high at 60% VO_2max, when participants sweated excessively. The posture or movement of participants caused small gaps to arise between the skin and urethane sponge tapes around the absorbent pads at body sites with a small curvature radius. It is possible that the pads absorbed sweat from the periphery during high-sweat conditions. The materials used as barriers and the size of the absorbent pads suitable for each body site can be optimized to facilitate more accurate measurements under all exercise conditions.

The ventilated capsule method has previously been reported to produce greater LSR values compared with the absorbent method [18]. In the ventilated capsule method, the influx of relatively cool air and forced evaporation may cause skin cooling, thereby reducing sweat rate. However, it also keeps the skin dry, and thus may cause an increase in the sweat rate. In this study, LSR_{ap} and LSR_{vc} at adjacent positions were in the same range, because of greater-than-expected LSR observed using the absorbent pads. There was little evidence of maceration on the skin surface after removing the pads; therefore, we assumed that the absorbent pads with a contact layer that prevented hidromeiosis increased skin temperature and sweat production by means of its heat insulation and the lack of evaporation [31]. While it is worth considering a method for tailoring the pads and making use of a fitted pad of appropriate size for the target body site, or its adaptive limit, these results supported that the absorbent pads could provide sufficient information about the mean LSR over a period of moderate intensity exercise.

Body sweat distribution was presented by the local sweat volume throughout the exercise. LSR_{ap} showed a symmetrical pattern: LSR_{ap} for the middle of the trunk was greater than that for both sides, while LSR_{ap} for the flank was lower than that for the front or back of the trunk. LSR_{ap} for the thighs and legs were lower than that for the upper arm. The LSR_{ap} for the front of the legs and thighs were higher than that for the back of these areas. These data indicating regional differences in LSR obtained throughout an exercise period was similar in trend to that obtained during brief exercise periods in previous studies [19,21,22].

Leg immersion test

	Sweat Rate (LSR_{vc})					Minute Percentage Sweat Rate ($\%LSR_{vc}$)			
		Time (min)				Time (min)			
	n	1-10	11-20	21-30	31-40	1-10	11-20	21-30	31-40
Young male	13	-	41.7 (5.5)	40.4 (3.5)	41.2 (3.0)	-	30.2 (6.6)	5.3 (1.0)*	6.8 (1.2)*
Older male	14	-	58.6 (7.0)	57.2 (4.9)	54.9 (3.6)	-	51.0 (8.7)	8.6 (1.1)*	9.6 (1.4)*
Young female	12	-	29.8 (3.7)	29.8 (4.4)	28.6 (5.0)	-	36.6 (9.4)	9.6 (2.6)*	7.0 (1.5)*
Older female	9	-	46.2 (10.1)	53.4(10.7)	56.4 (10.9)	-	53.3 (19.5)	23.2 (8.3)*	13.3 (4.1)*

Constant intensity exercise test

	Sweat Rate (LSR_{vc})				Minute Percentage Sweat Rate ($\%LSR_{vc}$)		
	Time (min)				Time (min)		
	n	1-10	11-20	21-30	1-10	11-20	21-30
35%VO_2max							
Prepubertal boy	6	-	24.8 (5.5)	22.7 (5.7)	-	4.7 (0.5)*	12.3 (1.8)*
Young male	9	-	26.7 (3.4)	26.6 (3.8)	-	5.4 (0.7)*	5.4 (0.6)*
Older male	5	-	28.0 (3.4)	28.8 (3.7)	-	9.8 (6.6)*	4.9 (0.4)*
50%VO_2max							
Prepubertal boy	6	-	40.7 (4.8)	38.3 (4.3)	-	9.4 (2.3)*	11.0 (2.0)*
Young male	9	-	41.8 (7.2)	41.2 (6.9)	-	2.2 (0.2)*	4.9 (0.6)*
Older male	5	-	51.2 (4.2)	51.4 (4.3)	-	2.0 (0.3)*	3.8 (0.3)*
65%VO_2max							
Prepubertal boy	4	-	48.5 (8.1)	45.5 (7.5)	-	20.0 (4.3)*	13.0 (1.5)*
Young male	9	-	43.7 (9.2)	49.0 (9.2)	-	4.6 (0.9)*	8.2 (1.3)*
Older male	5	-	60.1 (10.2)	66.0 (8.3)	-	4.2 (1.0)*	6.9 (1.0)*

Incremental exercise test

		Sweat Rate (LSR_{vc})						Minute Percentage Sweat Rate ($\%LSR_{vc}$)					
		time (min)						time (min)					
	n	1-10	11-20	21-30	31-40	41-50	51-60	1-10	11-20	21-30	31-40	41-50	51-60
Trained male	5	-	43.1 (6.8)	38.7 (5.2)	39.9 (4.2)	39.3 (2.6)	42.9 (2.0)	-	49.9 (11.4)	13.7 (3.0)*	5.5 (1.3)*	8.0 (1.6)*	12.6 (2.5)*
Untrained male	8	-	60.4 (7.4)	54.6 (6.4)	54.3 (5.5)	51.5 (4.3)	52.1 (3.1)	-	43.6 (11.3)	15.2 (4.1)*	7.7 (2.0)*	8.7 (1.6)*	15.0 (2.7)*
Trained female	10	-	38.4 (4.2)	35.1 (2.5)	36.4 (3.0)	33.9 (2.7)	33.0 (2.5)	-	43.2 (8.5)	13.9 (3.3)*	6.9 (1.3)*	6.5 (0.8)*	11.6 (1.2)*
Untrained female	9	-	39.8 (3.6)	44.7 (3.4)	45.5 (3.3)	44.0 (3.2)	43.1 (3.7)	-	56.6 (14.6)	14.9 (3.7)*	6.3 (1.9)*	5.0 (0.8)*	11.1 (1.6)*

Table 2: The coefficient of variation for the absolute sweat rate (LSR_{vc}) and the minute percentage sweat rate ($\%LSR_{vc}$) which was calculated by dividing the LSR_{vc} by the sum of the LSR_{vc} throughout the experiment. Values are mean (SEM). *$p<0.05$, significantly different from LSR_{vc}.

The absorbent pads used here may have covered a smaller sampling area than that of the absorbent materials used in the experiments by Smith and Havenith [21,22]. However, the pressure-related changes in LSR would be of little concern considering the absorbent pads used in this study, because the pads were fixed onto the skin by an extremely thin adhesive film.

Thus, the absorbent pads could provide reliable information about local sweat volume or mean LSR throughout the experiment. Information on time-dependent changes in sweat rate, for example, the discovery of stable LSR during exercise with a constant intensity, would allow the absorbent pad method to be more effective for the development of thermo-physiological modeling, sweating thermal manikin design, and clothing design. The differences in LSR among body regions could have more to do with peripheral function than central command. We hypothesized that the time-dependent changes in LSR at a single body site were equivalent to that at any other body site; therefore, it could be estimated from local sweat volume, measured by the absorbent pads, based on LSR_{vc} measured at any unclothed skin surface area by the ventilated capsule method. The results from 3 re-analyzed tests showed that LSR_{vc} largely varied between body sites, regardless of age, sex, and training. Conversely, the variation in $\%LSR_{vc}$ among the body sites was so small as to be insignificant. These results indicated that time-dependent changes in $\%LSR_{vc}$ were much the same at any body site; therefore, the time-dependent changes in LSR_{vc} at any body site could be used as a substitute for that at another body site. Moreover, the absorbent pads are easily placed on the subjects' skin and only 1 capsule needs to be fixed on a skin surface not covered by clothing. To estimate the time-dependent changes in LSR for various body sites, LSR_{vc} measured at any one site by using the ventilated capsule method was first converted to $\%LSR_{vc}$. Then, the time-dependent changes in LSR_{ap} could be estimated by multiplying LSR_{ap} determined using the absorbent pad by $\%LSR_{vc}$ measured by the ventilated capsule.

The absorbent method offers an easy-to-use and cost-effective approach for studies requiring determination of LSR. This method improves the collection of total sweat volume throughout the experiment and estimation of time-dependent changes in LSR. This procedure could open the possibility of applying the absorbent pad method in experimental or field tests involving clothed areas.

Conclusion

The agreement of the absorbent pads method with the ventilated capsule method was verified by a strong correlation between LSR_{ap} and LSR_{vc} at adjoining positions and by the comparable values of LSR_{ap} and mean LSR_{vc} within each exercise intensity group. An overview of local sweat distribution among 21 body sites throughout the entire 40-min exercise period could be obtained using the absorbent pad method. There were significant regional differences in LSR_{ap} within each exercise intensity group. The regional comparisons showed greater LSR_{ap} at the chest and back, and a lower LSR_{ap} at the flank, thigh, and legs. It also revealed that LSR_{ap} was distributed symmetrically and was greater in the middle compared to the sides. After re-analyzing data from our previous studies on LSR_{vc} in prepubertal boys, men, and women across a range of ages, LSR_{vc} were arranged in the order of lower limbs<upper limbs and trunk<forehead. Conversely, the minute percentage sweat rate (%LSR_{vc}), which was calculated by dividing LSR_{vc} by the sum of the LSR_{vc} throughout the experiment, were not affected by body site. Thus, the time-dependent changes in LSR_{vc} at a single body site was equivalent to that at any other body site; therefore, the time-dependent changes in LSR_{ap} at various sites could be estimated by multiplying LSR_{ap} by %LSR_{vc} measured at any one site. The absorbent pads could be placed on the skin at various sites, even those under clothing, and only a single ventilated capsule needed to be attached to unclothed skin. The procedure described here for estimating time-dependent changes in LSR_{ap} would enhance the versatility of the absorbent pad method in experiments aimed at improving the design of protective and athletic clothes.

Acknowledgements

We thank our volunteer subjects for their cooperation. This work was supported in part by Grant-in-Aid for Challenging Exploratory Research (JSPS KAKENHI Grant Number 22650172).

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