4. STUDIES IN STAMINA OF JUDOISTS (1)

T. Sasa (Tokyo Medico-Dental University), T. Asami (Tokyo University of Education) and M. Kaneko (University of Tokyo)

The interpretation of the term "stamina" differs according to the sport in question. The essential points of "stamina" required differ somewhat with the various kinds of sports, for example: a sport with a long duration (marathon, long distance running, long distance swimming, bicycle road race, etc.), a sport requiring and outburst of energy for a short duration (short distance running, short distance swimming, sumo, etc.), a match with an opponent and lasting for 3 to 6 minutes (Judo, wrestling, boxing, fencing, etc.) or a ball game requiring two opposing teams and lasting for a considerable length of time (soccer, volley ball, rugby, hockey, etc.). In other words, these may be divided into sports requiring stamina of the respiratory and circulatory systems, stamina of power, stamina of muscle strength, stamina of speed, or stamina of the nervous system. Prof. Ikai (University of Tokyo) holds the view that human reaction to muscular activity may be divided into aerobic and anaerobic reaction, and from this standpoint explains that, whereas in such sport as marathon in which endurance is of primary importance (aerobic reaction), in the "last spurt" or in strenuous competitive sport in which an outburt of energy is required, an anaerobic reaction is necessary, and whether the athlete has stamina or not depends on whether he has this reserve energy. Prof. Fukuda defines stamina as "physical fitness having enough latent force which enables the athlete to hold out against odds".

In Judo, the problem of stamina was given only slight consideration until February 1963 when the Soviet Judo group visited Japan and showed very energetic bouts which aroused great interest in the cultivation of stamina. Also, results of various measurements of physical fitness of the Judo paticipants in the 1963 Olympic Games indicated that fitness indices of the Harvard step test and muscle endurance test, both considered as indices of stamina were comparatively low, attesting to the lack of stamina in these athletes (Measurements of physical fitness of Judo participants in the 1964 Olympic Games. Judo, October, 1963). Thereupon, it was thought that it would help considerably in training Judo athletes to investigate into the actual conditions of stamina required by the athletes, and the cause of the lack of stamina in these athletes.

METHOD OF INVESTIGATION

In the present study, stamina was investigated from the standpoint of endurance of the circulatory and respiratory systems. A treadmill with an inclination of 8.6% was used, and the experimental subject was made to run on it at a constant speed until he was "all out", and the endurance time until "all out" was considered as the criterion of endurance.

As experimental subjects one athlete was selected from each of the three weight classes: light, middle, and heavy weight. Light weight athlete T.S., III-dan, an Olympic participant had registered 101.4 points on the Harvard step test and as a Judo athlete may be considered to possess an excellent cardiac function. Middle weight athlete T.Y., IV-dan, and heavy weight athlete K.M., IV-dan, although not Olympic participants both took part in the All Japan Judo Contest and may be considered first rate athletes. Their Harvard step test points were 89.3 and 87.7, respectively, and compare favorably with 87.8 and 85.0, the averages of the Harvard step test points of the middle weight and heavy weight athletes, respectively, measured in 1963. The values of various measurements of physical fitness of the three atheltes are shown in Table 1.

RESULTS AND DISCUSSION

1. Comparison with non-trainees.

Only a few reports are available regarding the study of the influence of body weight on endurance. By making an experimental subject weighing 99 kg. and another weighing 61 kg. walk or run on a treadmill, Robinson[1] made a comparative study of their energy metabolism, pulse rate, rectal temperature, skin temperature, and loss of body weight after exercsie. As a result , it was found that the

Table. 1 Measurements of the three Judoists.

	age	body height (cm)	body weight (kg)	chest circumference (cm)	subcutaneous fat (mm)	arm strength		leg strength		muscle endurance	vital capacity (cc)	Harvard test
						right (kg)	left (kg)	right (kg)	left (kg)			
light wgt.	19	161.1	65.5	87.5	5.0	34	—	52	45	45	3560	101.4
middle wgt.	24	168.2	81.5	102.0	11.0	66	58	88	96	58	4400	98.3
heavy wgt.	24	176.7	110.0	113.6	24.0	—	43.5	96	99	74	4600	87.7

Table 2. Comparison between Judoists and non-trainees (track and field athletes).

		body height (cm)	body weight (kg)	body area (sq. cm)	metabolic rate at rest
judoists	T.S. 19 age light wgt.	161.7	65.0	171.7	253
	T.Y. 24 age middle wgt.	168.2	81.5	193.0	273
	K.M. 24 age heavy wgt.	176.7	110.0	221.0	284
non-trainees	T.A. 26	169.0	67.0	178.4	265
	M.M. 26	163.0	66.5	171.7	251
	K.I. 30	164.0	64.5	173.2	251
	K.K. 26	165.5	58.0	166.1	248
	M.K. 24	166.0	57.0	163.8	215
athletes	H.G. 21	178.0	65.0	184.4	192
	K.T. 24	161.4	53.5	157.7	193
		maximum ventilation (L/minute)	oxygen uptake (L)	oxygen debt (L)	oxygen uptake +oxygen debt (L)
judoists	T.S. 19 age light wgt.	95.50	35.571	5.198	40.769
	T.Y. 24 age middle wgt.	97.45	22.149	5.534	27.683
	K.M. 24 age heavy wgt.	74.74	6.897	9.607	16.504
non-trainees	T.A. 26	52.48	7.843	1.693	9.536
	M.M. 26	67.87	3.427	1 978	5.405
	K.I. 30	70.93	11.303	2.246	13.549
	K.K. 26	71.42	8.516	2.126	10.640
	M.K. 24	66.03	7.800	0.979	8.779
athletes	H.G. 21	99.84	14.956	4.589	19.543
	K.T. 24	97.54	22.029	8.432	30 461

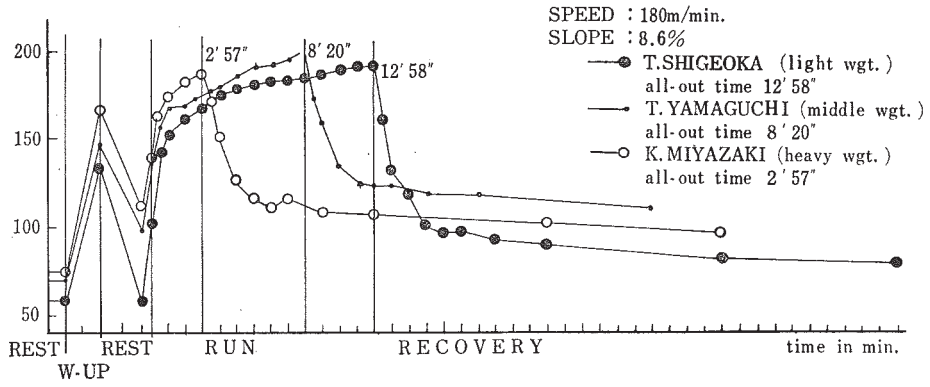
efficiency during the exercise of both subjects was identical. Dissipation of heat was restricted while the heavier subject was performing exercise at the energy metabolic rate of 8 cal./kg. per hour, because of a comparatively high room temperature of 32°C, and a high humidity of 70%, and consequently, after running for 75 minutes he was obliged to stop due to heat exhaustion. In comparison to this, the lighter subject under identical environmental conditions, reached a constant pulse rate while performing exercise at an energy metabolic rate of 9.7 cal./kg. and attained balance of production of body heat and heat dissipation. Since production of body heat is proportionate to body weight, the ratio of body weight to area of body surface was greater by 20% in the heavier individual than in the lighter individual, and consequently, the production of heat during exercise in the heavier individual was also greater by 20%. Robinson concludes that since the amount of heat dissipation is determined to a great extent by the area of body surface, the heavier individual reached a state of exhaustion even in an exercise in which the lighter individual was able to maintain a state of heat balance. In Judo, Sugimoto, Ogawa and associates made measurements of energy metabolism during defensive posture, fundamental Throwing technique and Katame technique, and it was found that in the transitional movements of the defensive posture the intensity of motion was very great with a relative metabolic rate of 13.5–18.2. They report that in the throwing technique, Hane-goshi registered the highest relative metabolic rate (4.3) and Ashi-harai the lowest relative metabolic rate (2.9), whilst the other throwing techniques registered intermediate values. Also, in general, the Ne-waza showed very high relative metabolic values (18–30).

Table 2 (continued)

speed m/min.	duration time	am't. of work (kgm)	am't. of work per min.	ventilation per min. during exercise	ventilation debt
180	12.58	13,336	1,026	75.12	101.40
180	8.20	10,652	1,279	70.13	146.34
180	2.57	5,093	1,726	65.18	173.45
190	5.24	5,668	1,050	41.49	103.36
180	2.51	2,944	1,033	41.79	112.17
180	5.54	5,960	1,010	55.71	114.36
180	4.15	3,863	909	53.52	118.09
180	5.01	4,480	892	42.10	43.01
260	4.51	7,150	1,474	81.98	175.41
260	6.58	8,453	1,213	74.63	110.41

oxygen uptake per min. L/min.	energy consumption cal./min.	cal./min.	cal./body wgt.	cal./body area	efficiency %
2.74	3.14	15.8	0.24	0.092	15.2
2.77	3.46	17.5	0.21	0.091	17.8
2.30	5.50	27.8	0.25	0.126	14.3
1.57	1.91	9.6	0.14	0.054	27.6
1.14	1.80	9.1	0.14	0.053	25.3
1.88	2.26	11.4	0.18	0.066	20.5
1.70	2.13	10.8	0.19	0.065	16.9
1.56	1.76	8.9	0.16	0.054	23.7
2.99	3.91	19.7	0.30	0.107	17.0
3.15	4.34	21.9	0.41	0.139	12.9

In the present study measurements of heart rate, expired air and oxygen consumption of the above mentioned three Judoists were made during and after treadmill run, and compared with those of non-trainees. Table 2 shows the endurance time and the reaction of the respiratory and circulatory systems of the three Judoists and those of non-trainees after running on a treadmill with 8.6% inclination at the rate of 180 m./min. until "all-out". Light weight athlete T.S. ran for 12 minutes and 58 seconds at the rate of 180 m./min. and showed the highest endurance. Middle weight athlete T.M. ran for 8 minutes and 20 seconds, whilst heavy weight athlete K.M. ran for 2 minutes and 57 seconds showing a considerable lower endurance than the average (4 minutes 49 seconds) of 5 non-trainees.



Ffg. 1 Pulse Rate in Treadmill Run

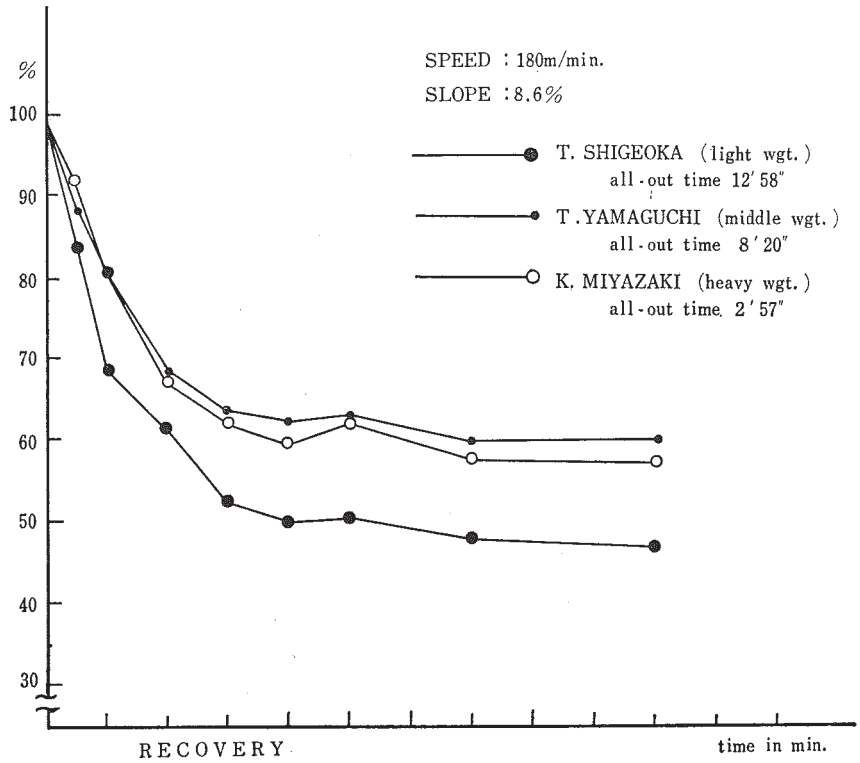


Fig. 2 Recovery Ratio of Heart Rate

The amount of mechanical work was the greatest in T.S. (13,336 kgm.) followed by T.Y. (10,652 kgm.) and K.M. (5,093 kgm.), whereas the amount of mechanical work per minute was the greatest in K.M. (1,726 kgm.) followed by T.Y. (1,279 kgm.) and T.S. (1,026 kgm.). Measurements of ventilation volume per minute, maximum breathing capacity, oxygen intake per minute, oxygen debt, and total energy consumption during exercise showed exceedingly higher values in the three athletes than in the non-trainees. Consequently, the energy consumed per unit body weight was considerably larger in the trained athletes.

2. Comparison among the three trained Judoists

Heart rate: Fig. 1 shows changes in heart rate of the three athletes in a treadmill all-out run. The heart rate at rest of T.S. was 58, which was the lowest of the three Judoists, whereas those of the other two were around 70. The heart rate of T.S. returned to normal level in the rest period following a warming-up exercise of 140 m./min. for 2 minutes exhibiting an excellent cardiac function. The heart rate at "all-out" of T.S. was 192, that of T.Y. 197, and that of K.M. 187, indicating that the limit level of K.M. was somewhat lower than the others. It is thought that the "all-out" of K.M. was not due to his reaching the limit of his cardiac function, but to other factors. A study of the recovery course of the three athletes revealed that the heart rate of T.S. recovered normal level very rapidly in spite of the fact that his endurance time was the longest and the amount of work the largest, attesting to the superiority of his cardiac function. The recovery ratio of their heart rate also revealed the superiority of T.S. over the others. K.M. was slightly better than T.Y., however, this is thought to be due to the difference in the amount of work, and consequently, due to the difference in the load on the heart, because the result of the Harvard test, under identical conditions, seem to indicate that T.Y. (89.3 points) was somewhat superior to K.M. (87.7 points).

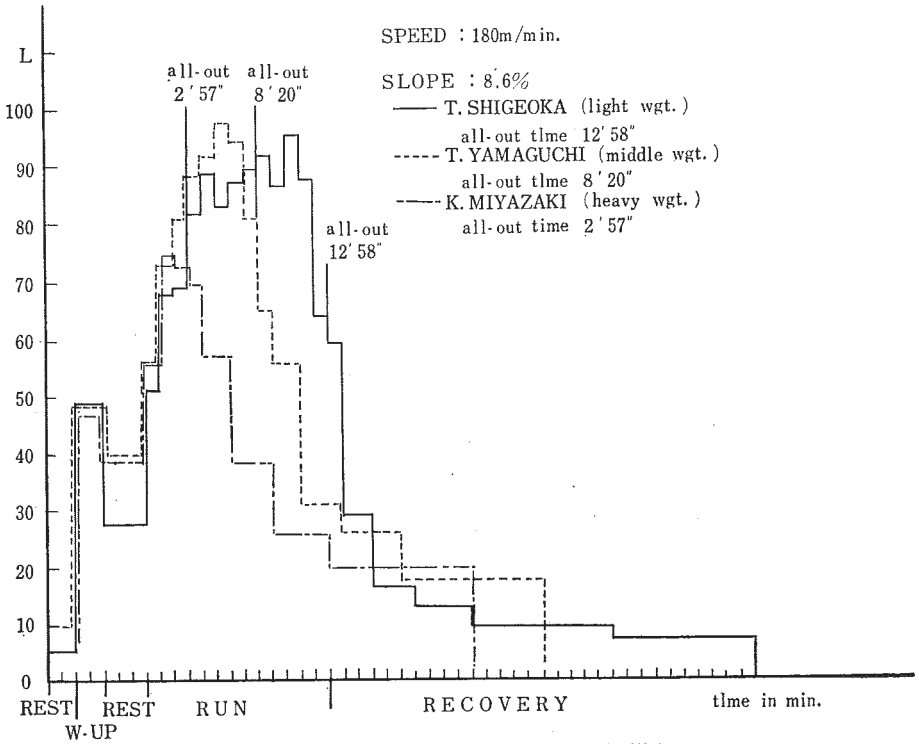


Fig. 3 Pulmonary Ventilation in Treadmill Run

Ventilation: The per minute ventilation amount of each athlete during exercise (excluding ventilation at rest), as shown in Table 2, was 75 L. in T.S., 70 L. in T.Y., and 65 L. in K.M., i.e., in the order of light weight, middle weight, and heavy weight. However, the order was reversed in the ventilation debt 20 minutes after exercise, i.e., in the order of heavy weight, middle weight, and light weight. These facts show that the venitilation of T.S. was the greatest of the three during exercise and that he recovered with the least amount of ventilation (Fig. 3)

The per minute maximum ventilation of both T.Y. and T.S. exceeded 95 L., however, that of K.M. was very low. In order to investigate whether this level showed the limit of the ability of each athlete, the per minute maximum ventilation, at rest, was measured and compared. As a result, it was found that the highest value (136 L.) was that of K.M., followed by that of T.S. (117 L.) and by that of T.Y. (99 L.), which indicates that T.Y.'s respiratory function was mobilized to the maximum limit during exercise.

Energy metabolism: The per minute oxygen consumption during exercise decreased in the order of light weight, middle weight, and heavy weight, whereas, the oxygen debt during the recovery period decreased in the order of heavy weight, middle weight, and light weight showing an identical tendency as that of ventilation (Fig. 4). Consequently, T.S. consumed the largest amount of oxygen during exercise, and his oxygen debt during the recovery period was the lowest of the three Judoists. This means that he possessed excellent aerobic capacity during exercise.

The per minute oxygen comsumption during exercise was the greatest in K.M. (5.5 L.) followed

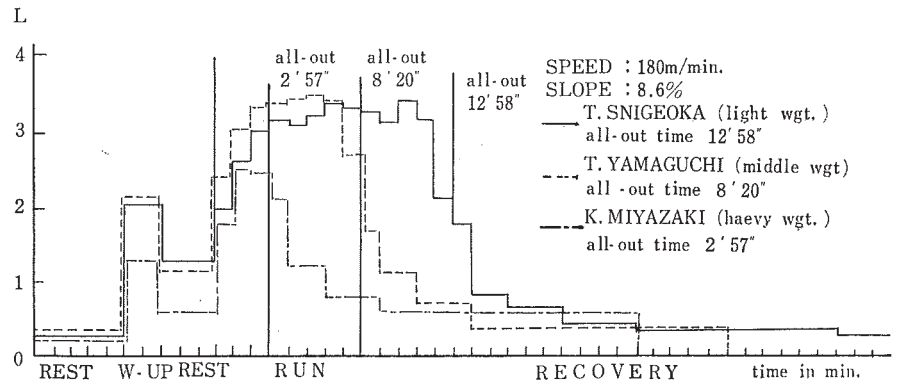


Fig. 4 O_2-Consumption in Treadmill Run

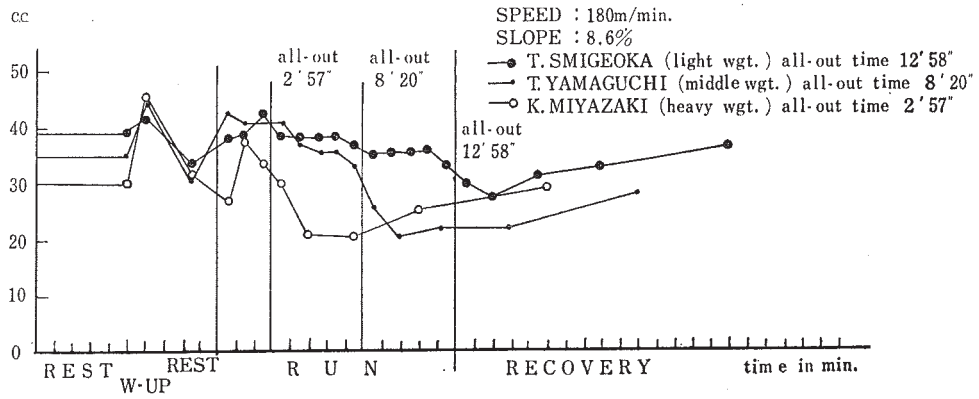


Fig. 5 O_2-Removal in Treadmill Run

by T.Y. (3.5. L.) and then by T.S. (3.5. L.). Caluculations of energy consumption per body weight or per body surface area during exercise also revealed the highest values in K.M. However, calculations of mechanical efficiency by using the equation: $E=\frac{W}{M-R}$ (E=efficiency, W=amount of work, M=total energy consumption, R=energy consumption during rest) revealed that the efficiency of K.M. was the lowest (14.3%) and that of T.Y. the highest (17.8%) followed by that of T.S. (15.2%). This may be understood, also, by comparing their rate of oxygen consumption (Fig. 5), which was the same (33 cc.) in all the three subjects at "all-out", however, during exercise, it was very low in K.M. There was a transient drop in the consumption rate in all the three experimental subjects after exercise, however, the drop in T.S. was comparatively mild attesting to the high efficiency of respiration in T.S.

Skin temperature: The accumulation of body heat, and the efficiency of heat dissipation are important factors influencing endurance in physical exercise. For example, assuming that the specific gravity of the human body is 0.82, the accumulation of body heat during exercise may be calculated by the following equation: $H=mc(t_2-t_1)$cal. (H=heat, c=specific heat, t=temperature). The production of body heat may be known from the measurement of rectal temperature, and the dissipation of body heat may be estimated from the measurement of skin temperature and from a careful scrutiny of sweating. The measurement of rectal temperature is often accompanied by pain and mental distress and it was thought that it might influence other measurements, and consequently, was omitted from this experiment. Instead, femoral skin temperature which is thought to indicate comparatively accurately changes in temperature of the lower extremity, was measured. This would enable a scrutiny of the balance of heat production and dissipation. As shown in Fig. 6 the femoral skin temperature began to drop from the inception of exercise for about 3 minutes in all the three ex-

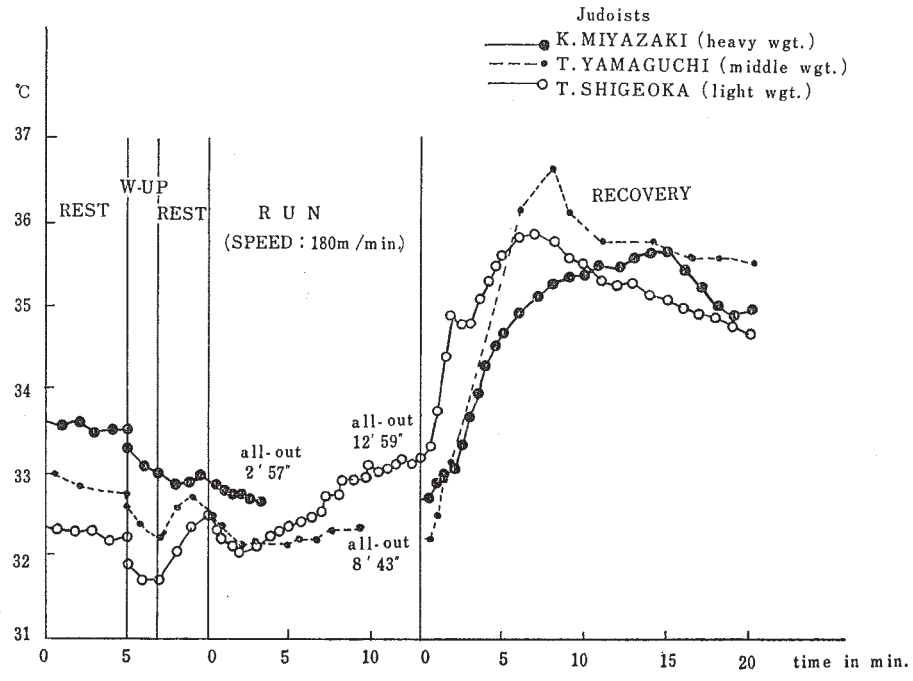


Fig. 6 Skin Temperature (Femur)

perimental subjects, and in K.M. reached "all-out" without seeing a rise in temperature. However, in T.Y. and T.S. femoral skin temperature began to rise from about 3 minutes following inception of exercise, and this rise in temperature was more pronounced in T.S. Consequently, it may be said that T.S. produced the greatest amount of heat during exercise and was able to endure its accumulation.

In the recovery period, a sudden rise in skin temperature was observed which indicated that vigorous dissipation of body heat was taking place. The highest increase in skin temperature was observed in T.S. followed by that in T.Y. and K.M.

CONCLUSION

From the foregoing study on the respiratory and cardiac functions of the three experimental subjects performing a treadmill run until "all-out", it was found that heavy weight athlete K.M., although having a large respiratory capacity could not fully display its function, and also that his respiratory efficiency was low. Also, from measurements of his femoral skin temperature, it became evident that his adaptability to counter heat accumulation by adequate dissipation was not being performed smoothly. Furthermore, from his heart rate it may be judged that he had not reached the limit of his cardiac function when he was "all-out", and the cause of his being "all-out" was not due to difficulties in his respiratory and cardiac functions, but due to other factors, for example, lack of speed adaptability of the leg muscles, inadequate blood supply to the leg muscles, or inadequate dissipation of body heat. Consequently, in order to improve the endurance of K.M. it is necessary, above all, to reduce his weight, thereby decreasing the load to his lungs, heart and leg muscles. This would increase efficiency and enable the organs to function more adequately. In middle weight T.Y., the cardiac and respiratory systems were functioning nearly to their limits, however, in view of the fact that the recovery of his heart rate and the rate of oxygen consumption were poor, it is suggested that in order to increase endurance, it is necessary to improve the various recovery processes. The cardiac and respiratory systems of T.S. showed excellent functioning, however, his slightly low mechanical efficiency requires some attention. Assuming the highest record time of endurance to be T.S.'s 12 minutes 58 seconds, it was thought to be of interest to calculate how many minutes T.Y. and K.M. had to run in order to perform the same amount of work as T.S. As a result it was found to be 10 minutes 26 seconds for T.Y., and 7 minutes 43 seconds for K.M., i.e., T.Y. had to run 2 minutes 6 seconds, K.M. 4 minutes 46 seconds longer than their respective records. In other words, in order to acquire the same endurance as T.S., it is necessary for T.Y. to undergo further training and improve his endurance by 25%, and for K.M. to improve by 162% which clearly shows the inferiority in endurance of heavy weight Judoists. Accoridng to Kajiyama[3], the distance of action of the Judoists during a Judo match lasting for 5 minutes is on the average 94 meters, and the average of the techniques performed is 24, and according to Sugimoto and Ogawa[2], as mentioned previously, the R.M.R. during Jigotai (defensive posture) is 13.5–18.2, during Nage-waza 2.9–4.3, and during Katame-waza 18–30, all of which prove that the energy consumed during a match is enormous. Since there is a tendency, at present, for the match time to lengthen and also for the number of matches to increase, the necessity of stamina becomes more and more urgent.

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4. STUDIES IN STAMINA OF JUDOISTS (2)

T. Sasa (Tokyo Medico-Dental University).
T. Asami (Tokyo University of Education)
and M. Kaneko (University of Tokyo)

Together with the training of technique, much importance has been laid, recently, on the cultivation of physical fitness in Judo, and various papers dealing with the subject have been reported. However, studies dealing with stamina in Judo from the standpoint of respiratory and cardiovascular functions are very few. Stamina is a basic requirement in order to effect one's technique efficiently during a match. It is quite evident from the results of studies on the heart rate during Judo practice made by Ikai and Kaneko[1], and also from measurements of energy exchange during execution of techniques in Judo made by Sugimoto and Ogawa[2] that the practice of Judo imposes quite a load on the respiratory and cardiovascular systems.

The present paper deals with a continuation of the study already reported last year[3], and was made in order to obtain further information regarding the stamina of Judoists. In the present study, also, such reactions as the heart rate and oxygen consumption were measured. Since only a few experimental subjects could be used due to technical difficulties the subjects used in the experiment were all well trained Judoists.

METHOD OF INVESTIGATION

Two heavy weight, two middle weight, and two light weight Judoists, totalling six were selected for the study. Four of these Judoists have had experience in participating in the All Japan Judo Contest, and especially, heavy weight Judoist A was a veteran of 5 years of successive participations in the contests. Of the remaining two Judoists, middle weight Judoist D had taken part in the Judo event of the All Japan Athletic Meeting when he was still in high school. A had the longest Judo career with 15 years, followed by C and D with 9 years each, B and E with 7 years each, and then by F with 4 years, indicating that they were all well qualified Judoists. All these Judoists are at present actively practicing Judo.

The experiments were conducted in the laboratory of the Department of Physical Education, University of Tokyo, from November 1965 to January 1966. Each experimental subject was made to perform two treadmill runs in different speeds (180 m./min., 200 m./min., in A only 160 m./min, 180 m./min.) twice (once daily). The inclinations of the running board was 8.6% (ca. 5°). The reserve strength of the respiratory and cardiac functions of each Judoist was compared after a 5 minute run at the rate of 180 m./min.

The following measurements were made for approximately 40 minutes before, during, and after the treadmill run, in order to investigate heart rate, respiratory rate, pulmonary ventilation and oxygen uptake: a) E.C.G. by means of a bipolar thoracic lead, b) respiratory curve by means of a thermister, c) collection of expired air by means of a Douglas bag.

Table 1

	exp. subject	age	dan (grade)	body wgt.	body hgt.	chest	subcutaneous fat	vital capacity	maximum ventilation (STPD)	Judo career
			dan	kg	cm	cm	mm	cc		
heavy weight	A	26	5	92	171.0	105.0	34.0	5300	85.7	15 years All-Japan championship(5)
	B	21	4	85	177.0	98.5	7.5	5220	96.4	7 years All-Japan championship(1)
middle weight	C	33	4	79	167.5	100.5	10.0	5360	85.0	9 years All-Japan championship(1)
	D	21	4	74	170.2	105.0	9.0	5020	88.5	9 years
light weight	E	21	3	66	164.0	89.3	11.0	3840	99.2	7 years All-Japan championship(1)
	F	19	2	66	168.0	93.7	24.0	4660	90.1	4 years NationalAtheletic Meet(1)

Table 2

	exp. subject	running speed (m/min.)	running endurance time	mechanical work (kgm)	maximum pulse rate (beats/min.)	※※ maximum oxygen uptake (*l*/min.)	$\frac{\text{maximum } O_2}{\text{body wgt.}}$ (cc/min/kg)
heavy wgt.	A	160 180	4′13″ 2′20″	5097 3165	211 206	3.533	38.7
	B	180 200	5′00″※ 3′20″	6273 4641	182 181	4.371	51.4
middle wgt.	C	180 200	4′28″ 2′45″	5214 3563	186 183	3.370	42.7
	D	180 200	4′34″ 2′20″	4995 2827	185 180	3.864	52.0
light wgt.	E	180 200	5′00″※ 4′09″	4871 4495	184 187	3.005	45.6
	C	180 200	5′00″※ 5′01″	4871 5432	180 182	3.578	54.7

※ 5′ run ※※ maximum values of 2 speeds

RESULTS AND DISCUSSION

(I) Endurance running time.

As shown in Table 2 only B (heavy weight), E (light weight) and F (light weight) attained the required 5 minutes in the 180 m./min. run. The two middle weight Judoists were in the 4 minute level. whilst heavy weight Judoist A ran for only 2 minutes and 20 seconds. Even when the speed was lowered to 160 m./min. A could not attain the time made by the other Judoists running at 180 m./min. The records of the 200 m./min. in all the Judoists (excluding A) were their respective all-out time. The rating was in the order of F (light weight), E (light weight), B (heavy weight), C (middle weight), and D (middle weight) disclosing that the first two were light weight Judoists. The light weight Judoists, by virture of their lighter body weight have advantage over the others with regard to en-

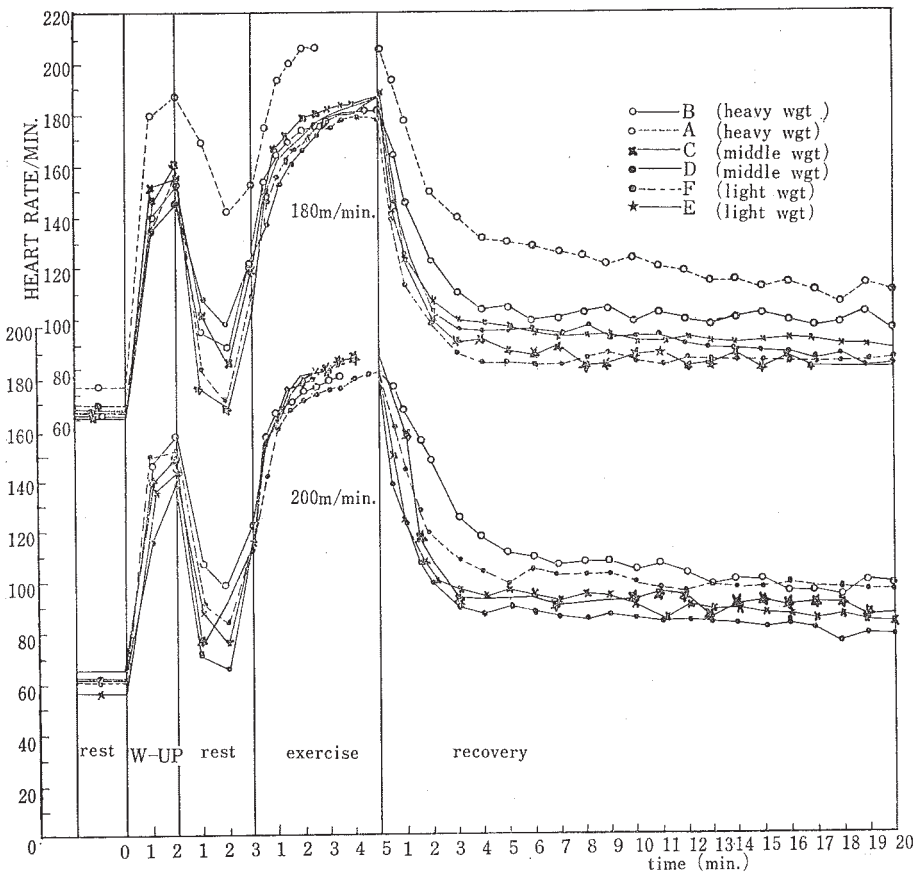

Fig. 1 Pulse rate in Treadmill Run.

durance running time from the viewpoint of performance. However, it is noteworthy that heavy weight Judoist B made better time than the two middle weight Judoists.

It was thought to be of interest to compare the endurance running time of these Judoists to that of the non-Judoist. According to measurements made by Ikai and Kagaya[4], the averages made by non-Judoists of varying age groups in the 180 m./min. treadmill run were: 5 minutes for the 13—14 year group; 8—9 minutes for the 15—16 year group; and 10 minutes for the 17 year group. Also, as cited in a previous report[8], one university student in every five could not attain 5 minutes. In other words, insomuch as treadmill running time was concerned, half of the number of the experimental subjects used in the present study could not attain the average level of the non-Judoists in general.

(II) Mechanical work.

In order to eliminate the effect of differences in body weight, the result obtained in each experimental subject was converted into mechanical work (Table 2). Although there are certain difficulties in the calculation of mechanical work from results obtained in a treadmill run, a simple method was adopted in the present study, i.e., the vertical distance (height) attained by a run over an inclination of 5° was multiplied by the body weight. When results of an all-out run of 200 m./min. were compared, the following rating was obtained: F (light weight), B (heavy weight), E(light weight) .....disclosing that although light weight Judoist E obtained better results in endurance running

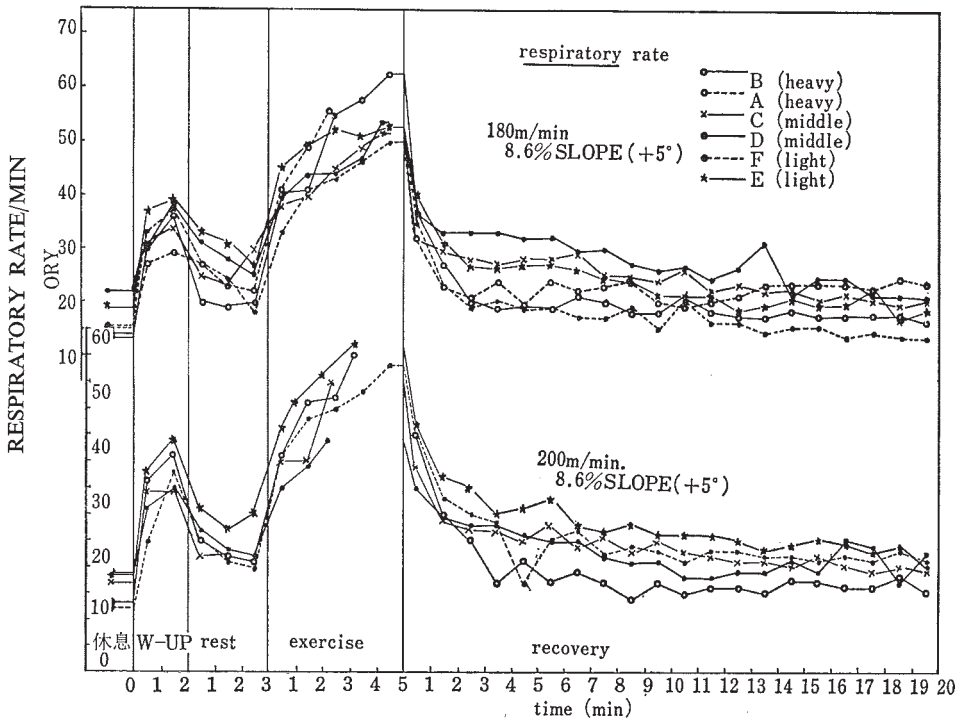

Fig. 2 Respiratory rate in Treamill Run.

time than heavy weight Judoist B, the latter excelled in mechanical work. The mechanical work done by the other heavy weight Judoist A was comparatively small, and consequently, his poor rating of the endurance running time cannot be entirely due to the disadvantage of his being heavily built.

Heart rate.—The upper and lower curves in Fig. 1 illustrate heart rate of the Judoists before, during, and after performing the 180 m./min., and the 200 m./min. runs, respectively. In the 180 m./min. run, the increase in heart rate of heavy weight Judoist A is particularly noteworthy. His heart rate reached 188 per minute, already, during the warming-up period, and during the actual treadmill run a maximum rate of 206 per minute was recorded. Furthermore, the recovery rate was slower than in the others, attesting to the fact that his cardiac function was remarkably inferior compared to the other Judoists. Judging from his heart rate alone, his treadmill running time, although comparatively short, may be considered to be his limit of endurance.

Light weight Judoist F showed the lowest heart rate during the 5 minute run, and his recovery rate was also very rapid indicating that he had ample reserve strength. B (heavy weight) and E (light weight) both ran for fully 5 minutes, however, the recovery rate of E was somewhat faster than that of B. The recovery time of heart rate after the 180 m./min. run was shorter in the lighter weight Judoists, however, the two middle weight Judoists and A (heavy weight) did not run fully for five minutes, and consequently, the amount of mechanical work was different. Thereupon, the rapidity of the recovery of heart rate was computed with reference to the total amount of mechanical work, and it was found that the recovery rate was the fastest in B.

In the 200 m./min. run F passed the 3—4 minute time with a comparatively low heart rate and reached the heart rate level of the other Judoists when he was all-out at 5 minutes and 1 second. This reserve energy in F as indicated by his heart rate is one of the reasons behind his comparatively long endurance running time. The all-out time in the 200 m./min. run differed in every one of the experimental subject, so that the recovery rate of the Judoists could not be compared.

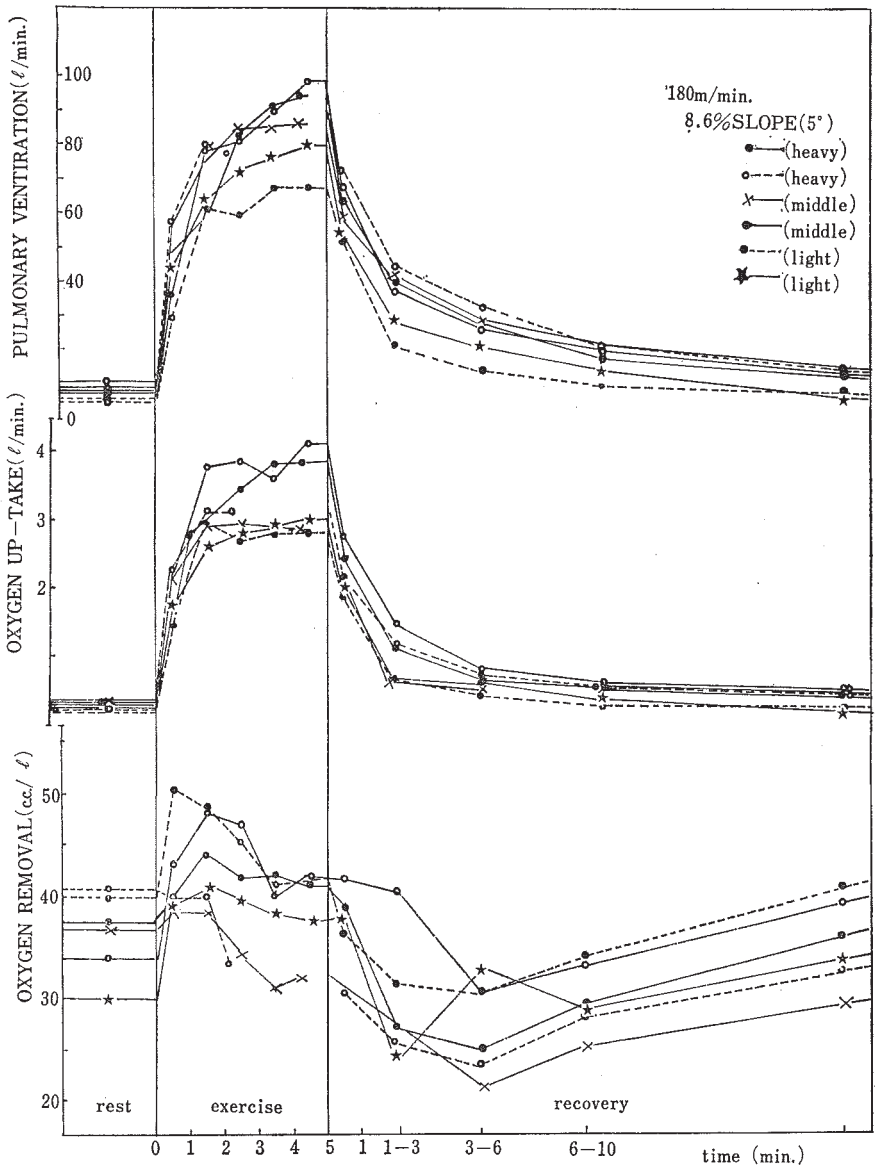

Fig. 3 Pulmonary ventilation, oxygen uptake, oxygen removal during Treadmill Run.

(III) Respiration rate.

The respiration rate of F in comparison to the other Judoists was the lowest during the 180 m./min. run, and his recovery rate was very rapid (fig. 2). This respiration rate when compared to the 200 m./min. all-out run is considerably low, indicating his reserve strength. In contrast to this, heavy weight Judoist B showed a very high respiration rate. Generally, a high respiration rate during exercise indicates a low efficiency in ventilation[5], however, in B's case, increase in respiration rate was accompained by an increase in pulmonary ventilation to a considerably high level, and his recovery rate was also very rapid. This seems to indicate that B is endowed with the advantageous constitution of acquiring larger amounts of oxygen by virtue of increased ventilation accompanying

increased respiration rate. In contrast to this, the respiration rate of E (light weight) during exercise was high, and his recovery rate was slow, leaving much room for improvement in his respiratory function.

(IV) Pulmonary ventilation, oxygen uptake, oxygen removal.

Pulmonary ventilation, oxygen uptake, and oxygen removal during the 180 m./min. run are shown in Fig. 3. Pulmonary ventilation was low in the light weight Judoists and high in the heavy weight Judoists. B, notwithstanding his heavy weight, ran fully for 5 minutes, and his mechanical work was also very large. The reason behind his excellent rating is his high pulmonary ventilation and his high oxygen removal, thus enabling a high oxygen uptake. On the other hand, in heavy weight Judoist A, the pulmonary ventilation alone was comparatively high, however, his oxygen removal was low, resulting in poor oxygen uptake. The low rating in endurance time in A's case was not only due to his poor heart rate, but also to his inadequate oxygen uptake. Although F's (light weight) ventilation was low, he compensated for this by his high oxygen removal, thus enabling his oxygen uptake to be on the same level as that of E or C. Especially, in F's case, the maximal oxygen uptake per unit body weight, which is considered to be an important criterion of endurance time, was very high, and together with his excellent heart rate, may be considered to be important factors contributing to his high rating in the endurance running time. The oxygen uptake of the two light weight Judoists following exercise was comparatively low indicating that the oxyge ndebt during exercise was also low. This is also an important factor contributing to prolonging the endurance running time.

(V) Comparison of oxygen uptake of Judoists and non-Judoists.

Fig. 4 shows the oxygen uptake of the experimental subjects and the averages of oxygen uptake of students in general. From Fig. 4 (a) it will be seen that the maximal oxygen uptake of Judoists as on a higher level than that of the students in general, however, when calculated in terms of unit body weight (Fig. 4 (b)) the oxygen uptake level was not necessarily higher than that of the students in general. The maximal oxygen uptake of B showed the highest level, however, when calculated in terms of unit body weight, his oxygen uptake was practically on the same level as that of the students in general, and when A's oxygen uptake was calculated in terms of unit body weight, it was found to be considerably lower than the level of the students in general. For a good performance in an endurance run, it is necessary for the athletes to have a high level of oxygen uptake per unit body weight.

From the foregoing studies on the heart rate, respiration, and oxygen uptake of 6 Judoists, it has been found that their endurance capacity is not necessarily on a high level and that much remains to be improved. It is hoped that this study will urge reappraisal of the problem of endurance among Judoists.

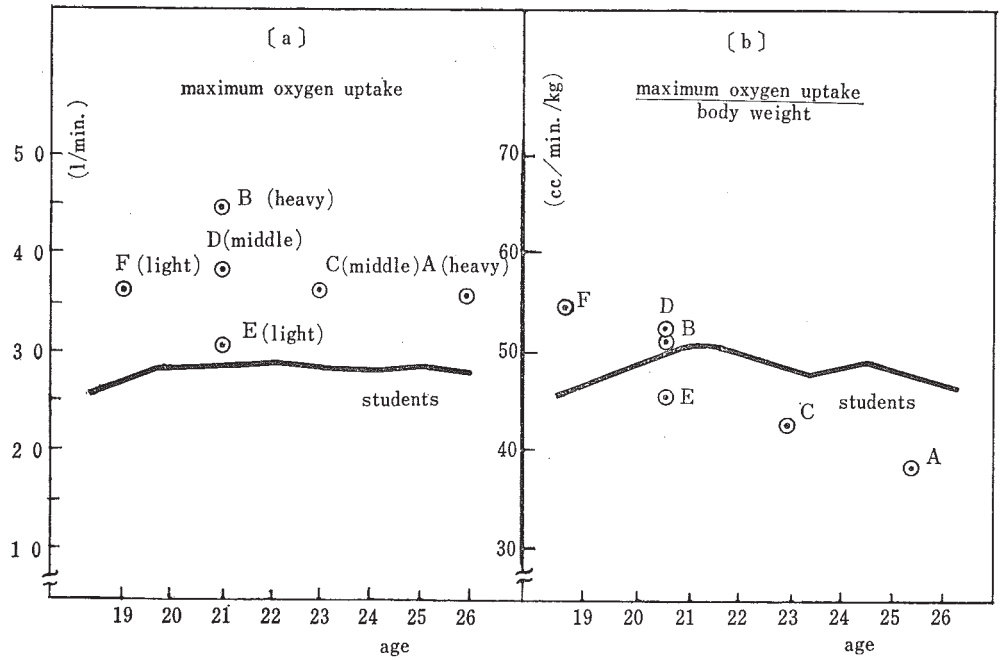

Fig. 4 Comparison of maximum oxygen uptake between judoists and students.

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