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Research article

PHYSIOLOGICAL RESPONSES DURING MATCHES AND PROFILE OF ELITE PENCAK SILAT EXPONENTS

Abdul Rashid Aziz ✉, Benedict Tan, Kong Chuan Teh

Sports Medicine & Research Centre, Singapore Sports Council, Singapore

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ABSTRACT

This is a descriptive, cross-sectional study describing the physiological responses during competitive matches and profile of elite exponents of an emerging martial art sport, pencak silat. Thirty exponents (21 males and 9 females) were involved in the study. Match responses (i.e. heart rate (HR) throughout match and capillary blood lactate concentration, [La], at pre-match and at the end of every round) were obtained during actual competitive duels. Elite silat exponents' physiological attributes were assessed via anthropometry, vertical jump, isometric grip strength, maximal oxygen uptake, and the Wingate 30 s anaerobic test of the upper and lower body, in the laboratory. The match response data showed that silat competitors' mean HR was > 84% of estimated HR maximum and levels of [La] ranged from 6.7 – 18.7 $mMol^{-1}$ during matches. This suggests that competitive silat matches are characterised by high aerobic and anaerobic responses. In comparison to elite taekwondo and judo athletes' physiological characteristics, elite silat exponents have lower aerobic fitness and grip strength, but greater explosive leg power (vertical jump). Generally, they also possessed a similar anaerobic capability in the lower but markedly inferior anaerobic capability in the upper body.

KEY WORDS*:* Martial art, competition demands, Wingate, pencak silat

ELİT PENCAK SİLATCILARIN GÖRÜNÜMÜ VE MÜSABAKALAR SIRASINDA FİZYOLOJİK YANITLAR

ÖZET

Bu, bir savaş sanatları sporu olan elit pencak silat sporcuların görünümü ve müsabakalar sırasındaki fizyolojik yanıtlarını tarif eden tanımlayıcı, kesitsel bir çalışmadır. Otuz (21 erkek ve 9 kadın) sporcu çalışmaya dahil edildi. Maç yanıtları (yani kalp atım sayısı (HR) maç boyunca ve kapiller kan laktat konsantrasyonu [La] maç öncesinde ve raund sonlarında) gerçek yarışma sırasında değerlendirildi. Egzersiz testleri labarotuvarda yapıldı ve gerçek müsabakalar sırasındaki fizyolojik yanıtlar değerlendirildi. Elit silat sporcuların fizyolojik özellikleri labarotuvarda antropometri, dikey sıçrama, izometrik kavrama kuvveti, maksimal oksijen alımı, alt ve üst ekstremite için 30 san'lik Wingate testleri ile değerlendirildi. Maç verileri silat yarışmacıların maç sırasında ortalama HR'lerinin tahmini maksimal HR'in >%84'ü ve [La] düzeyleri ise 6.7 –18.7 $mMol^{-1}$ değerleri arasında olduğunu gösterdi. Bu, silat maçların yüksek aerobik ve anaerobik özellikler içerdeğine işaret etmektedir Elit tekvando ve judo sporcularının fizyolojik özellikleri ile karşılaştırıldığında elit silat sporcuların daha düşük aerobik kapasite ve kavrama kuvvetine sahipken daha büyük bacak gücüne (dikey sıçrama) sahiptir. Genel olarak, silatcılar alt ekstremite için benzer anaerobik güce karşın üst ekstremite için daha düşük aerobik kapasiteye sahipti.

ANAHTAR KELİMELER: Savaş sanatı, yarışma gereksinimleri, Wingate, pencak silat.

INTRODUCTION

Many Asian martial art forms are becoming popular in the Western hemisphere (Theeboom and De Knop, 1999). One form that is gaining international recognition is pencak silat, or simply silat. This art of self-defense is indigenous to the ethnic Malays and has its origins in South East Asia, dating as far back as the 13th century (Ku Ahmad and Wong, 1978). Historically, silat was practiced by the native people in their struggle against their colonial rulers. With the withdrawal of the latter, silat gradually turned into a cultural activity and was used for ceremonial and recreational purposes. This traditional art form had since been modified into a structured competitive sport. The sport's world controlling body, the International Pencak Silat Federation includes member countries such as the US, Japan and many European nations (International Pencak Silat Federation, 1999). There are various internationally sanctioned competitions such as the European Championship inaugurated in 1985, South-east Asian Games (since 1987) and World Championships (since 1982). These competitions have been held in many non-traditionally silat countries like Austria, Belgium, Netherlands and Thailand, and the fact that global participation in these competitions has increased substantially speaks well of its worldwide following and acceptance.

The sport of silat consists of two categories, artistic and contact. The former focuses on choreographed movements and patterns of silat. The latter is a weight-categorised, full-contact, unarmed duel of similar concept to other conventional martial art sports like taekwondo and judo. Here, two silat exponents square-off on an eight metre diameter circle area. The match consists of three rounds of two minutes each with one-minute interval between rounds. Time stoppages by the referee are not included in the actual bout time, so the actual duration of each round and thus total match time is usually longer than the two and eight minutes scheduled, respectively. Points are awarded for toppling an opponent, successful defensive blocks, and offensive punches and kicks to the chest, abdomen and flanks, leg sweeps and throws (International Pencak Silat Federation, 1999). Only strikes with either the arms or legs are considered legal. Unlike other competitive martial arts, the launch of any attack and defence movement must be initiated with specific co-ordinated silat "step patterns", otherwise the points subsequently score will not be valid. The exponent scoring the highest number of points or knocks his opponent out, wins. (see Video 1, Video 2 and Video 3; available from URL: http://www.jssm.org)

Knowledge of the physical demands of the sport and physiological characteristics of its elite athletes may help to facilitate the development of specific training programmes for optimal performance in the sport. No such data have been published with regards to the sport of silat. Thus the primary purpose of this study is to investigate the physiological responses during competitive contact-matches and characteristics of its elite contact-type exponents. A secondary aim is to compare silat data with published data of taekwondo and judo.

METHODS

Subjects

The study was divided into two parts, a laboratory- and field-measures involving two groups of subjects. Laboratory measures consisted of 10 male and 5 female members of the silat team that represented Singapore during a major international competition. They have competed at international-level between two to fifteen years. Included in this sample were three males and two females who were former world and regional champions. The participants in the field measures were twenty-two exponents (16 male and 6 female) out of the possible 26 finalists in a local competition. Out of this cohort, 16 were later selected to join the national training squad. In both components of the study, silat exponents involved were from various weight-classes. The two groups' physical make-up is summarized in Table 1. Although the two parts of the study were conducted a year apart, seven volunteers (5 males and 2 females) were involved in both components of the investigation. Thus a total of 30 athletes were involved in the entire study. Informed written consent and permission were obtained from all athletes and the organizing committee for the field measures, respectively.

Procedures

The laboratory assessment consisted of several exercise performance tests to determine the physiological attributes of elite silat exponents. The tests were conducted three weeks prior to the 1999 South-east Asian Games, and in which the team won two gold, three silver and five bronze medals. The field measures involved the determination of HR and [La] of silat athletes during the finals of the local National Pencak Silat 2000 Championship.

Field Measures

The matches of the Championship finals were held in a gymnasium, on standard competition mats. All matches were held on the same day, from 2 to 6 p.m. and temperature ranged from 27-30 °C and humidity was between 64-70%. During the pre-match

weighing-in, a HR transmitter belt was strapped around the athlete's chest. The receiver watch (Accurex Plus, Polar Electro Oy, Kempere, Finland) was placed in a small pouch and securely strapped to the athlete's body armor protection near the shoulder blade area. The HR data, stored at 5 s intervals, was later downloaded for analysis. [La] was measured at pre-match (i.e. taken ~5 min prior to match and athlete would had completed his/her pre-match warm-up) and at post-round (i.e. within 15 s at the end of each round of the match). Blood sample was taken via finger-prick and measured with a portable lactate analyzer (Accusport, Boehringer Manneheim, Germany).

Table 1. Physical characteristics of silat exponents involved in the laboratory- and field- component of the study. Data are mean (SD).

	LABORATORY		**FIELD**	
	Male (n = 10)	**Female (n = 5)**	**Male (n = 16)**	**Female (n = 6)**
Age (yrs.)	24.4 (4.4)	24.6 (3.9)	22.6 (3.3)	23.1 (3.1)
range	17.7 – 31.8	20.8 – 29.0	18.0 – 27.6	21.0 – 29.1
Height (m)	1.72 (0.8)	1.57 (0.4)	nm	nm
range	1.56 – 1.86	1.51 – 1.62		
Body mass (kg)	71.1 (14.4)	57.0 (8.4)	68.8 (13.6)	55.7 (7.4)
range	50.3 – 97.1	48.0 – 69.8	49.3 – 92.0	47.0 – 64.0
Body fat (%)	11.3 (5.4)	23.4 (3.6)	nm	nm
range	4.0 – 21.1	20.3 – 28.4		

nm = not measured.

Laboratory Measurements

The chosen exercise performance tests were deemed to be relevant to the sport of silat. Each subject completed all tests over an entire morning session in the following order: vertical jump, isometric grip strength, maximal oxygen uptake, and anaerobic test of the upper and lower body; with sufficient rest allowed between tests. Athletes were familiar with test protocols since these tests were part of the team's fitness monitoring program.

Height and body mass were measured with an electronic scale (708 Seca, Hamburg, Germany). Percentage body fat was calculated from skinfolds: subscapular, biceps, triceps and suprailiac (Durnin and Womersley, 1974) with a Harpenden caliper (Quinton Instrument, Seattle, USA). The chalked-finger method of the Sargeant jump (with a counter movement action) test, best of three attempts, was used to measure the athlete's lower extremity explosive power (in cm). Forearm grip strength was determined using an electronic dynamometer (T.K.K. 5101 Takei, Tokyo, Japan) with standardized protocols. The highest measurement, of three trials for each hand, was taken as the grip strength for that hand (in Newtons, N).

Maximal oxygen uptake (VO_{2max}) was determined with a continuous, incremental treadmill run (1900 Marquette, Milwaukee, USA). After a standardized warm-up, testing commenced with a treadmill velocity of between 8 to 12 $km \cdot hr^{-1}$, at 0% grade; with a lower speed for females. Treadmill elevation was increased by 2% each minute for the first 5 min and subsequently by 1% every minute thereafter until subject's attained exhaustion. Metabolic gases were recorded every 20 s using a metabolic cart with an open circuit system (SensorMedic 2900Z, Yorba Linda, California, USA). Gas analyzers were calibrated prior to each run with known concentrations of standard gases and flowmeter was calibrated using a 3-l syringe. VO_{2max} is the highest oxygen consumption within a 20 s interval when at least two of the following criteria were achieved: (i) RER of > 1.1, (ii) > 95% of estimated maximum heart rate (HR_{max}), and (iii) volitional exhaustion. HR was continuously monitored via short distance telemetry (Accurex Plus).

The Wingate 30 s (WG) anaerobic test was used to determine the anaerobic capability of the upper and lower body (Inbar et al., 1996). A friction-braked cycle ergometer with a pan-weighted loading system (834E Monark, Verberg, Sweden), fixed with an optical sensor and computerized software (OptoSensor 2000^{TM}, Sport Medicine Industries, St. Cloud, USA) was used. For the upper body assessment, the ergometer was clamped on a platform half-metre above ground and handgrip rollers were used whilst for the lower body test the ergometer was anchored to the ground with toe-clips. There was a minimum of 30 min of rest instituted between the upper and lower body test. All tests were preceded with a standardized warm-up and followed with two trials of 2-3s effort to accustom athletes with the set resistance, and

another 5 min of passive rest. For the test, athletes started slowly and then began peddling or cranking fast against an unloaded ergometer. Within 2-3 s, the weighted-basket was released and data collection initiated. Pacing was not allowed and strong verbal encouragement was given for athletes to maintain their maximal pedal/crank rate throughout the test. Resistance set for the lower body test was 0.01 and 0.008 kp·kgBW^{-1} for male and female respectively; and 0.005 and 0.004 kp·kgBW^{-1} for upper body. Test data averaged over 1 s were measured for Peak Power: highest power over the first few seconds of the test, and Mean Power: average power exerted over 30 s.

Statistical Analysis

The Statistical Package for Social Sciences (SPSS v. 10, Inc. Chicago, IL) was used for all descriptive statistics.

Table 2. Heart rate and blood lactate responses of male and female silat exponents during actual competitive matches.

	Heart Rate (beats·min^{-1})			**Blood Lactate (m·Mol^{-1})**				**Match (min)**
	Rd 1	**Rd 2**	**Rd 3**	**Pre-M**	**Post-Rd 1**	**Rd 2**	**Rd 3**	
Males	**(n = 13)**			**(n = 14)**				
Mean (SD)	174 (10)	186 (7)	190 (8)	2.2 (0.7)	8.8 (1.3)	11.2 (1.6)	12.5 (2.1)	12.0 (4.0)
Females	**(n = 5)**			**(n = 6)**				
Mean (SD)	165 (14)	174 (11)	181 (10)	1.9 (0.5)	9.7 (2.3)	12.8 (3.5)	13.1 (4.0)	12.5 (0.4)

Rd = round; Pre-M = pre-match.

RESULTS

Table 2 is a summary of silat athetes' physiological responses during matches. For analysis of the match characteristics, the duration of *a round* includes all formal breaks (e.g. umpire breaking the fight-contact and time-outs) and informal stoppages within the round (e.g. injury). *Match duration* is the total time taken to complete all three rounds, including the 60 s interval between rounds. When analysing the match responses, HR data of three athletes (two males and a female) appeared erratic and were discarded. Another match (male) ended before the regulation time, with a throw-down technical knockout early in the first round; and consequently the two exponents' HR and [La] data were also eliminated from the analysis. For calculation of the athlete's mean HR for each round, data taken during the 60 s rest intervals between rounds were disregarded. This gives a more accurate reflection of the cardiovascular workload placed upon the athletes during match. Tables 3 and 4 show the silat exponents' exercise performance tests result in the laboratory.

DISCUSSION

This study is an initial attempt at examining the physiological responses during actual competitive duels and describing the physiological parameters of elite silat exponents. These athletes included those who have achieved considerable success in the international arena. Furthermore, measurements were taken close to their peak of preparedness. Elite silat exponents' physiological attributes data were then compared with athletes of taekwondo and judo. These martial art sports were chosen because of their worldwide recognition and Olympic-sport status. Also, according to an expert view (S Allau'ddin, personal communications), some of the techniques and movements used and their athletes' physiological traits may possibly have some similarities with silat. Such comparisons are thus relevant and provide a useful preliminary perspective of the "physical prowess" of a silat exponent relative to other martial arts athletes. These comparisons are however, only descriptive in nature and thus caution is advised when interpreting the results.

Field Measures

The silat fight pattern is typically "start-stop" nature and despite the wide fluctuations in intensity between work and pause periods during a bout, the HR profile did not appear to exemplify this intermittent pattern (Figure 1). The HR increased rapidly at the start of each round and was oscillating close to the silat exponent's estimated HR_{max} without any substantial decline throughout match except for the in-between rounds break. This HR trend of relatively constant "steady-state" is usually observed during continuous-type exercise. Interestingly though, such stable HR readings had also previously been found during other intermittent-type of exercise with very short (< 15 s) work to rest period (Saltin et

al., 1994) as well in taekwondo matches (Heller et al., 1998).

Measurement of HR has frequently been used as a reliable index of average exercise intensity during intermittent exercise (Ali and Farrally, 1991; Heller et al., 1998). Based on the individuals' estimated HR_{max} (using formula: 220 minus age), the mean HR indicated that the male and female silat exponents were operating between 89-97% and 84-92% of HR_{max} throughout the match, respectively. This range of match HR intensity is comparable to that observed during competitive taekwondo matches (Heller et al., 1998), although different methods of determining athletes' HR_{max} were used. It must, however, be noted that the HR measurements were taken during actual competitive conditions, during the finals of a major competition. Thus the silat exponents were under enormous pressure and consequently a psychological effect that could artificially elevate the HR workload cannot be discounted. Nevertheless, the overall intensity of a silat match indicated exertion intensity close to the individual's maximal cardiovascular responses that was sustained throughout most of the match. This implies that the silat exponent requires a well-developed cardio-respiratory system.

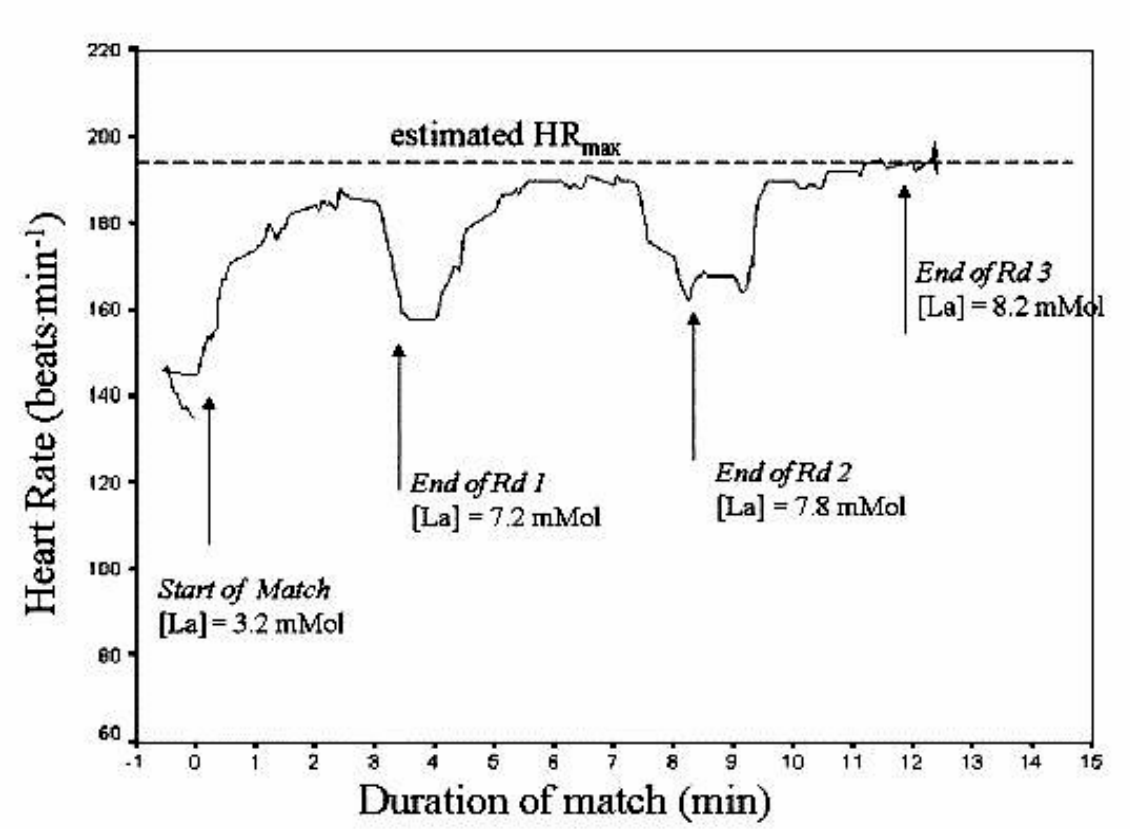

Figure 1. Typical heart rate and blood lactate response during a competitive match of a male silat exponent. Rd = round, [La] = capillary blood lactate concentration.

Silat competition rules state that an exponent is allowed up to four consecutive punches and/or kicks to the opponent during a single attack, upon which the referee immediately breaks off the confrontation (International Pencak Silat Federation, 1999). This suggests that silat exponents are accustomed to numerous bursts of high force production for 2-5 s, alternating with relatively lower-intensity movements throughout match. With regards to the metabolic demands of activity, a single brief maximal exertion (< 6 s) would derive the majority of the energy from anaerobic sources (i.e. phosphagens and glycolysis) whilst the contribution of the aerobic system is minimal (Gaitanos et al., 1993). Since this is a time-limit event and exponents will attempt to score as many points as possible, the fight-contacts are thus frequent and often interspersed with very short recovery duration. Consequently, during consecutive contacts, the phosphagens will not be completely restored and with time, lead to a progressive depletion of the phosphagens. As a result, there will be a greater reliance on anaerobic glycolysis to supply the energy requirements as the match progresses. This is clearly supported by the high mean post-round [La] data (Table 2). In fact, all the post-round lactate samples taken during the competition (N = 60) indicated high values, ranging

from 6.7 to 18.7 mMol·L^{-1}. Moreover, the single measurement taken at end of the round, as in this study, may well under-estimate the prevailing [La] level since it has been established that lactate produced by working muscles is continuously being oxidized by adjacent muscles during the exercising and rest periods (Brooks, 2000). Thus the consistently high [La] data corroborates with our contention of a dominant involvement of the anaerobic sources, particularly anaerobic glycolysis, during silat matches. It is interesting to note that although there are clear differences in the fight-pattern between the various martial art forms, the [La] levels observed during silat matches were similar to competitive taekwondo and judo matches (Heller et al., 1998; Sikorski et al., 1989).

Table 3. Aerobic fitness (VO_{2max}, ml·kg·min^{-1}), grip strength (Newton) and vertical jump (cm) - comparative data of silat exponents with athletes from taekwondo and judo. Data are mean (SD).

	N	VO_{2max}	Grip Strength*	Vertical Jump	Reference
Males					
Silat, Singapore National	10	52.1 (4.4)	435 (79)	59.9 (5.8)	Present study
Taekwando, USA Club	14	44.0 (6.8)	508 (81)	na	Thompson and Vinueza, 1991
Taekwando, Australia Club	17	52.0 (11.1)‡#	458 (57)	na	Kim and Jin, 2001
Taekwando, Czech National	11	53.9 (4.4)‡	555 (76)	45.4 (4.5)	Heller et al., 1998
Taekwando, USA Olympic	na	55.8 (3.9)	na	na	Pieter, 1991
Judo, Canada Provincial	17	53.8 (5.6)	566 (89)	na	Little, 1991
Judo, Poland Club	15	50.1 (6.5)	na	na	Sikorski et al., 1989
Judo, Poland National&	58	57.6 (4.6)	na	na	Borkowski et al., 2001
Judo, Poland National¥	17	55.6 (3.2)	na	na	Borkowski et al., 2001
Judo, Australia National	8	53.2 (5.7)§	na	52.0 (8.0)	Tumilty et al., 1986
Judo, Canada National	22	59.2 (5.2)	553 (65)	55.0 (9.5)	Thomas et al., 1989
Judo, Canada National	19	57.5 (9.5)	na	na	Taylor and Brassard, 1981
Judo, Korea National	10	62.8 (5.9)	na	58.1 (5.6)	Kim et al., 1996
Judo, USA National	18	55.6 (1.8)	na	na	Callister et al., 1991
Judo, Belgium National	24	na	na	52.5	Claessens et al., 1986
Females					
Silat, Singapore National	5	43.1 (3.3)	271 (58)	40.8 (4.0)	Present study
Taekwando, Czech National	12	41.6 (4.2)‡	369 (45)	37.9 (3.4)	Heller et al., 1998
Taekwando, USA Olympic	na	47.0 (7.8)	na	na	Pieter, 1991
Judo, Canada Provincial	8	43.7 (3.5)	312 (57)	na	Little, 1991
Judo, Poland National&	49	50.7 (5.5)	na	na	Borkowski et al., 2001
Judo, Poland National¥	18	49.9 (4.8)	na	na	Borkowski et al., 2001
Judo, USA National	9	52.0 (1.4)	na	na	Callister et al., 1991
Judo, Korea National	10	50.5 (6.9)	na	na	Kim et al., 1996

VO_{2max} = maximal oxygen uptake; *data reflect the highest mean value of either the left/right or dominant hand; na = data not available; ‡on a cycle ergometer; #estimated from Astrand nomogram, &athletes representing Poland from 1994-1997; ¥athletes representing Poland from 1998-1999; §on an air-braked arm-cycle ergometer.

It can be observed that there were progressive increases in mean HR and mean [La] as the match progresses (Figure 1 and Table 2). The HR drift could possibly be due to effects of dehydration since silat exponents practice dehydration techniques prior to competition to make weight (Allau'ddin, personal communications), a similar ritual as in other martial-art sports (Fogelholm et al., 1993; Kim, 2001). The rise in mean [La] suggests an accumulation of lactate due to increase in activity and/or exertion. Obviously, towards the end of match, the athletes were intensifying their efforts to score as many points possible to influence the match outcome. The comparable mean HR (expressed as % estimated HR_{max}) and [La] between male and female exponents suggest that male and female matches were equally intense.

Laboratory Measures

Data describing the physiological capabilities of elite players of the sport may reflect the demands of the sport. Table 3 showed that silat exponents' mean VO_{2max} is similar to the taekwondo and judo club-level athletes, but is clearly lower when compared to

the martial arts' national-level exponents. A possible reason for this lower aerobic fitness could be that training for silat performance is out-dated since it was based on old, traditional methods handed down from previous practitioners (Allau'ddin, personal communications). These methods tend to place great emphasis on repetitive skill-related movements rather than specific aerobic conditioning and this may have a negative consequence on their long-term aerobic prowess. Given the importance of high aerobic fitness for rapid recovery from bursts of high-intensity anaerobic efforts (Tesch and Wright, 1983), the present silat exponents may need to further enhance their aerobic fitness.

Table 4. Wingate 30 s anaerobic test of the lower and upper body – comparative data of silat exponents with athletes from taekwondo and judo. Data are mean (SD).

	N	Peak Power ($W \cdot kg^{-1}$)	Mean Power ($W \cdot kg^{-1}$)	Reference
LOWER BODY				
Male				
Silat, Singapore National	10	12.3 (0.8)	9.3 (0.7)	Present study
Taekwondo, Czech National	11	14.7 (1.3)	11.5 (0.9)	Heller et al., 1998
Taekwondo, USA Olympic	na	11.8 (2.0)	9.2 (1.2)	Pieter, 1991
Judo, Canada National	22	13.7 (1.1)	10.6 (0.7)	Little, 1991
Judo, Poland National[&]	58	12.4 (0.8)	9.0 (0.8)	Borkowski et al., 2001
Judo, Poland National[¥]	17	12.5 (0.9)	9.1 (0.6)	Borkowski et al., 2001
Judo, Korea National	10	9.0 (0.9)	7.3 (0.5)	Kim et al., 1996
Female				
Silat, Singapore National	5	9.7 (0.7)	6.7 (0.2)	Present study
Taekwondo, Czech National	12	10.1 (1.2)	8.1 (0.8)	Heller et al., 1998
Taekwondo, USA Olympic	na	10.1 (2.4)	7.9 (1.2)	Pieter, 1991
Judo, Poland National[&]	49	10.7 (0.8)	8.0 (0.6)	Borkowski et al., 2001
Judo, Poland National[¥]	18	10.6 (0.6)	7.8 (0.5)	Borkowski et al., 2001
UPPER BODY				
Male				
Silat, Singapore National	10	6.2 (0.6)	4.9 (0.6)	Present study
Judo, Canada Provincial	17	8.5 (0.7)	5.6 (0.5)	Little, 1991
Judo, Canada National	22	11.3 (0.8)	8.7 (0.8)	Thomas et al., 1989
Judo, Israel National	na	~7.8 (0.3)	~5.8 (0.2)	Inbar et al., 1996
Female				
Silat, Singapore National	5	4.1 (0.5)	3.3 (0.4)	Present study
Judo, Canada Provincial	8	5.9 (0.9)	4.0 (0.6)	Little, 1991

[&]athletes representing Poland from 1994-1997; [¥]athletes representing Poland from 1998-1999; na = data not avaliable.

The silat athletes' mean absolute grip strength is substantially lower than those of other martial arts (Table 3). While it is possibly advantageous to possess a strong grip to out-manoeuvre or throw an opponent, more often than not, silat matches are won by accumulating points through other non-grasping means like kicking and punching (Allau'ddin, personal communications). This was also evident from analysis of the competition final-matches where there was only one technical knockout out of 13 matches observed. It may then be argued that in silat, the need to tightly grip the opponent may not be critical as in other martial arts e.g. judo. And accordingly, quick and explosive limb movements are much more crucial in many silat striking skills. This is partly supported by the vertical jump test where the male silat exponent showed the highest lower limb explosiveness compared with that of other martial art athletes (Table 3). The female silat exponents also showed a higher vertical jump than female taekwondo athletes; unfortunately the paucity of the availability of the female data preclude a definite conclusion with regards to their explosiveness.

The data in Table 4 indicate that silat athletes generally have a similar level of Peak Power and a slightly lower Mean Power during the WG lower body test in comparison to elite taekwondo and judo

exponents. This suggests that silat exponents possess high levels of anaerobic power capability of the lower body, but perhaps should be well-advised to further improve their ability to sustain the high power for a longer duration. For the WG upper body test, there is no data on taekwondo athletes. Thus relative to national-level judo athletes, the male and female silat exponents have a much lower upper body Peak and Mean Power. As mentioned previously, there is a great tendency for silat exponents to primarily use their lower limbs during duels and the subordinate upper limbs' anaerobic performance is a possible reflection of this emphasis. In contrast, judo primarily uses techniques that involve considerable upper body strength and power in gripping, grappling and arm-locking to execute body-throws or take-downs (Pulkkinen, 2001).

CONCLUSION

The present investigation describes the physiological attributes of exponents and match responses during actual competitive duels of an emerging martial art sport, pencak silat. It appears that a silat match is characterized by high anaerobic and aerobic metabolic responses, although conclusions concerning the contribution of the various metabolic pathways requires a more detailed investigation. In comparison with elite judo and taekwondo athletes, the elite silat exponents have better explosive leg power and comparable ability to perform short duration high-intensity exercise in the lower body; but possessed a lower grip strength, aerobic fitness, and anaerobic upper body capability.

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AUTHORS BIOGRAPHY:

Abdul Rashid AZIZ
Employment:
Head, Human Performance Laboratory, Sports Medicine & Research Centre, Singapore Sports Council
Degrees:
Diploma in Physical Education, Institute of Education, Singapore; Bachelor of Physical Education (Distinction), University of Alberta, Canada.
Research interest:
Exercise and sports performance training and testing
E-mail: abdul_rashid_aziz@ssc.gov.sg

Benedict TAN
Employment:
Sports Physician & Deputy Director (Sports Science), Sports Medicine & Research Centre, Singapore Sports Council
Degrees:
Bachelor of Medicine and Bachelor of Surgery (Singapore), Master of Sports Medicine (Australia)
Research Interests:
Sports medicine and sports science in general
E-mail: benedict_tan@ssc.gov.sg

Kong Chuan TEH
Employment:
Director & Consultant, Sports Medicine & Sports Science, Sports Medicine & Research Centre, Singapore Sports Council
Degrees:
Bachelor of Medicine and Bachelor of Surgery (Singapore), Master of Sports Medicine (USA)
Research Interests:
Sports medicine and sports science in general.
E-mail: teh_kong_chuan@ssc.gov.sg

✉ **Abdul Rashid AZIZ**
Sports Medicine & Research Centre, Singapore Sports Council, 15 Stadium Road, National Stadium, Singapore 397 718