Physiological and Muscle Actions Assessment of Windsurfers

Raymond C. H. So
The Hong Kong Sports Institute

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Summary

The aim of the project was to obtain a physiological and muscle action profile of elite windsurfers. Participants of the project included World Championships and Olympic Gold medalists from Hong Kong and overseas. There were four parts to this project. Each part was focused on a single aspect as described below:

Part 1 Physiological profiles of elite windsurfers
Part 2 Kinematics analysis of fatigue during continuous pumping action
Part 3 Muscle action analysis during isokinetic knee and elbow extension
Part 4 Comparison of fatigue pattern and windsurfers

A summary of findings for each part is presented below.

Part 1 : Physiological profile of elite windsurfers

Ten elite level (male = 5, female = 5) windsurfers were assessed physiologically. The height and weight measurement ranges for this group of athletes are 174-176 cm and 65-67 kg for males and 165-167 cm and 57-60 kg for females. As both height and body weight play important roles in helping the athlete achieve a biomechanic advantage against forces generated by wind and water, the narrowness of height and weight measurement ranges among these athletes suggested that there might be an optimal status for the sport. To verify this speculation, further research with more elite athletes will be needed.

The oxygen consumption rate for this group of athletes is about 59.8 ml/min/kg and 48.4 ml/kg/min for males and females respectively. When compared to athletes of other endurance sports, the windsurfers exhibited a lower level of aerobic endurance. However, in terms of muscle strength, they exhibited high strength levels in the knee muscles, trunk muscles and hand muscles. Hence, it appears that the sport makes greater demand on the athletes' muscle system than the central oxygen transportation system.

Part 2 : Kinematics analysis of fatigue during continuous pumping action

Six Hong Kong windsurfers from the national squad performed one three minutes all out pumping movement on a windsurfing pumping simulator. The windsurfing simulator allows the athletes to perform a pumping action normally employed by them during a Downwind situation in natural environments. The whole process of the three minutes pumping were filmed and one pumping cycle was selected at around the 5 th second of the pumping movement and at around the 175 th second of the movement. Kinematics data of these two cycles were compared to identify the changes of major joints movement pattern across time.

The results showed that hand movement speed, reflected by the speed of movement of the sail, decreased significantly after about 3 minutes of maximal pumping action. This suggested that fatigue was experienced in some or all major active muscles. There were also decreases in the range of movement and the speed of movement. When joints were compared for degree of changes, it was found that the wrist and ankle showed statistically significant drops in both measures.

Conclusively, it would appear that: 1) in the pumping action, the brachioradialis was fatigued the most, and 2) after 3 minutes of pumping, a drop in the ankle movement reflects a drop in the lower body muscles power.

Part 3 : Frequency spectrum analysis during repeated isokinetic knee and elbow extension

Ten subjects performed knee extension and elbow flexion maximally for about one minute at 180 deg/sec and 240 deg/sec respectively. Surface EMG was used to monitored the involved muscles continuously and the work output of each movement was also recorded.

When the mean and median frequency spectrum of the EMG were plotted against the work output of each movement, a statistically significant relationships were found between the drop of mean frequency spectrum and the drop of work output. A similar significant relationship was found between the median frequency spectrum and the drop of work output.

Based on plotted data, it was noticed that the standard deviation of the average relative mean and median frequency of each tested muscle was kept constant between 100% and 60% of relative work output. However, lower than 60% of relative work output, the standard deviation rose sharply and became close to being over the average mean and median frequency. From this, we may assume that when the work output drops more than 60 %, the relationship pattern of mean and median frequency drop and work output drop observed during higher work output values, breaks down. Also, based on this observation, it would appear that EMG mean and/or median frequency could be used to indicate muscle fatigue (drop of 40% muscle work output).

Part 4 : Application of surface EMG in assessing muscle fatigue pattern in repetitive dynamic sport movement

As the mean (median) frequency spectrum was found (Part 3) to be valid in noting muscle fatigue experienced under dynamic conditions, this method was used to identify the muscle fatigue pattern of the major working muscles in Windsurfing Pumping. These muscles were brachioradialis, biceps, mid-deltoid, rectus abdominis, latissimus dorsi, quadriceps, hamstring and gastrocnemius. Two Hong Kong elite windsurfers pumped maximally on a windsurfing pumping ergometer for 3 minutes, and the surface EMG for the eight muscles were recorded for the whole period. Comparison of muscle patterns were made in each pumping cycle. By analysing the mean (median) frequency spectrum in relation to the work time, a pattern of muscle fatigue was identified. This fatigue pattern represents the muscle utilization pattern at different work times.

When the muscle fatigue patterns of the two windsurfers were compared, they were found to be different. This suggested that the two windsurfers employed different muscle patterns for this task. Windsurfer A involved all muscles at the start of the pumping action and gradually built up to maximum work output at about the end of the second minute. After that, all the measured muscles showed evidence of fatigue. Windsurfer B activated muscles in rotation. All muscles were activated at the first 30 seconds, then, at the second 30 seconds, all muscles, except brachioradialis and quadriceps, went into a less active state. At the third 30 seconds, the brachioradialis went into almost complete rest while the quadricpes worked for another 30 seconds more. During the drop of brachioradialis activity, the mid-deltoid increased its involvement to maintain power output for 30 seconds. It then rested for 30 seconds before continuing for another 30 seconds when the 3 minute pumping action task was terminated. The back muscles were more involved at the latter half of the pumping movement.

Part 1

Physiological characteristics of elite windsurfers

Introduction

Athletes participating in different sports and specializing in different events or positions in a single sport, vary in body size and physique. That means, specific sport places specific demands on participant. Therefore, there are typical profiles for top competitors and fitness requirements for success in high level competitions (16) . Sapega et al. (19) stated that studies done at the Institute of Sports Medicine and Athletic Trauma indicated repeatedly that there were many characteristics and quantifiable musculoskeletal differences between athletes of different sports.

In the past, study on the physiological condition or requirement for sailing is rare. This may be because it seems that sailing requires low energy cost. As Bernardi et al. (2) stated that from the Sports Medicine perspective, sailing exercise does not appear to deserve special attention for avoiding danger to the cardiovascular system, at least in light weather conditions. But it had been found that sailors who were in windsurfing had different physiological characteristics to those in other Olympic sailing classes. Plyley et al. (15) found that the predicted average VO_{2max} of boardsailors (i.e. windsurfers) of the Canadian National Yachting Team was 51.9 ml/kg/min which was higher than the sailors from other categories of craft by about 7 ml/kg/min in average. In the same study, the authors also documented that the boardsailors were shorter and lighter by about 8.6 cm and 14.3 kg respectively in comparison with other sailors. Hence, it is worthwhile to further investigate the physiological characteristics of windsurfers. Furthermore, windsurfing was characterized by a great static effort which was particularly great when the wind exceeds force 5-6 knots (12). But with the recent rule changes in the Olympic course in windsurfing, notably the allowance of continuous pumping to aid progress, greater physiological or physical stress is placed on the athletes. Therefore, there is a need to build up sport-specific data file or profile that quantitatively document the range of physical characteristics and capabilities of windsurfers. These profiles are important in setting the goal of physical training programs. Moreover, physiological profiling has considerable application in developing a better understanding of the requirements of a sport and profiling is one of the more common strategies for identifying contributors to skilled performance. The windsurfing coach can develop specific training programs according to the specific requirement.

Method

Ten windsurfers who were representing Hong Kong and other countries (New Zealand, United Kingdom and People of Republic China) in major games and international level competition during the testing time, and with at least five years of professional training, volunteered to participate in the study. Among the subjects, five of them had got the title of World Championship in the last five years and three of them hold the title of Olympic Gold medalist in the past two Olympic Games. Informed consent was obtained from all subjects before testing. All tests were conducted at the Human Performance Laboratory of the Hong Kong Sports Institute (HKSI).

Height and weight were measured by a stadiometer (Holtain Ltd., Britain) and a weighing machine (Detetco, U.S.A.) respectively. A Harpenden skinfold caliber (Quinton Instrument, U.S.A.) was used to take the skinfold measures at triceps, thigh, suprailium, abdominal and chest (male only). Percentage body fat was estimated based on these skinfold measurement (8). Force vital capacity, forced expired volume in one second (FEV_1) and maximal voluntary ventilation (MVV) of the subjects were assessed by a Vitalograph-Compact spirometer (Vitalograph, Buckingham, UK). The sit and reach test was used to assess lower back and hamstring flexibility. The static hand grip strength of both hands were measured by Grip Dynamometer (Takei & Co. Ltd.) with elbow straight and the dynamometer pointing downwards.

Maximal oxygen uptake was measured using a continuous running test performed on a Quinton 65 treadmill (Quinton Instrument, U.S.A.). All subjects were familiarized with the testing procedures before data collection. After a 10 minutes warm up at 5 mile per hour (0% grade), the subjects began running at a velocity of 8 mile per hour (0% grade) for male and 7.5 mile per hour (0% grade) for female. Every 2 minutes thereafter, the grade was increased by 2.5% until volitional exhaustion. Metabolic and respiratory measurements were obtained using a Gould 2900 Energy Expenditure Unit (Sensormedics, U.S.A.) and included ventilation (VE), oxygen uptake (VO_2) and carbon dioxide production (VCO_2) which were computed every 20 seconds.

Front access cycle ergometer together with Super-Monitor (Repco Cycle, Australia) was used to measure subjects' anaerobic work capacity. The detail procedure had been described by Telford et al. (22) elsewhere. Briefly, the subjects were required to perform maximal effort standing cycle test for 10 seconds to assess work capacity from alactic system. After rest for 2 minutes, the same subject was required to do the same activity for 30 seconds in order to assess his/her work capacity from lactic system.

A Cybex 6000 (Lumex, U.S.A.) was used to measure maximal muscle capacity of extension and flexion muscles of knee joints under isokinetic condition. For the trunk extension and flexion test, a Cybex TEF Back System (Lumex, U.S.A.) was used. For each movement test, the subject firstly had 10 minutes of warming up on a stationery bike (Monark, Sweden) at a work load (watts) equal to the subject's body weight (kg). After setting the apparatus for the appropriate joint movement, the subject was stabilized with straps to the testing apparatus. All settings were adjusted according to User's Guide, Cybex 6000 Testing & Rehabilitation System (5) and Handbook of Cybex TEF Back System (6). For each joint movement test, the joint's axis of rotation was aligned with the input shaft of the dynamometer. The subject then underwent a warm up session at 60 deg/sec. Warm up consisted of three to five submaximal, and two maximal contractions and followed by a 30 seconds rest period. The test included five maximal repetitions. A 15 minutes rest period was allowed between different joint movement.

Result

Table 1 describes the physical characteristics of the subjects. The mean age of the male (n=5) and female (n=5) was 26.0 years and 25.2 years respectively. The male windsurfers were heavier. taller and thinner than the female subjects.

Table 1. The average (s.d.) physical characteristics of the subjects..

Sex	**Age (years)**	**Height (cm)**	**Weight (kg)**	**Body fat (%)**
M (n=5)	26.0 (1.9)	175.1 (2.8)	67.3 (3.1)	6.8 (2.2)
F (n=5)	25.2 (2.7)	166.2 (4.5)	59.2 (3.6)	19.2 (5.4)

Table 2 lists the pulmonary function condition of the subjects. The male and female subjects had similar FVC and FEV_1 results, which were 5.34 l for male and 5.31 l for female in FVC measurement, while in FEV_1 measurement, the male subjects scored 4.40 l and the female subjects scored 4.30 l. But for MVV result, the male subjects (190 l/min) were significantly higher than the female subjects (158 l/min).

Table 2. Mean (s.d.) pulmonary function measurement of the elite windsurfers.

Variables	**Male**	**Female**
FVC (l)	5.34 (0.29)	5.31 (1.76)
FEV_1 (l)	4.40 (0.48)	4.30 (0.94)
MVV (l/min)	190 (27)	158 (32)

Table 3 depicts the performance of these athletes in sit & reach test, as well as isometric hand grip strength test. The scores obtained were 37.8 cm for the male subjects and 39.1 cm for the female subjects in the sit & reach test. Their right and left hand grip test results were 56.7 kg and 35.5 kg respectively for the male subjects, and 39.4 kg and 35.5 kg respectively for the female subjects. For both male and female subjects, there were no significant differences in their right and left hand grip strength.

Table 3. Mean (s.d.) sit and reach, and static hand grip strength scores of the subjects.

Variables	**Male**	**Female**
Sit and reach (cm)	37.8 (5.3)	39.1 (4.2)
Grip strength - Right (kg)	56.7 (6.2)	39.4 (6.5)
Grip strength - Left (kg)	55.3 (6.1)	35.5 (9.9)

Table 4 depicts the mean values for their maximal oxygen uptake (VO_{2max}) and anaerobic power tests results. The absolute VO_{2max} result was 4.02 l/min for the male subjects and 2.80 l/min for the female subjects. Maximal heart rate (HR_{max}) achieved in the test of VO_{2max} were 191 bpm (male) and 194 bpm (female). The results of anaerobic capacity assessment (alactic and lactic) from leg exercise indicated that the present subjects generated 115 joules/kg and 105 joules/kg for male and female subjects respectively in the alactic work capacity test; for the lactic work capacity test, they generated 289 joules/kg in male and 261 joules/kg in female subjects.

Table 4. Mean (s.d.) maximal oxygen uptake results and anaerobic work capacity of the subjects.

Variables	**Male**	**Female**
VO_{2max} (l/min)	4.02 (0.55)	2.80 (0.18)
VO_{2max} (ml/kg/min)	59.8 (7.9)	48.4 (2.5)
HR_{max} (bpm)	191 (6)	194 (2)
VE (l/min)	128 (23)	102 (5)
Alactic work index (joules/kg)	115 (0.5)	105 (9.4)
Lactic work index (joules/kg)	289 (22.1)	261 (18.0)

Table 5 lists the peak torque output relative to body weight in the joints action of the knee and trunk. The mean left knee extension peak torque was 3.02 Nm/kg for the male subjects and 2.64 Nm/kg for the female subjects, that of the right knee extension was 3.12 Nm/kg for the male and 2.68 Nm/kg for the female. As with the hand grip test, the results of both sides knee tests for both sexes had no significant bilateral differences. In the test of trunk, the mean score for the trunk extension was 5.52 Nm/kg for the male and 5.12 Nm/kg for the female; for the trunk flexion, the male subjects scored 4.11 Nm/kg and the female subjects scored 3.21 Nm/kg.

Table 5. Mean (s.d.) peak torque outputs (Nm) of the knee and trunk from the elite windsurfers.

Joint movement	**Male**	**Female**
Right knee extension	3.12 (0.39)	2.68 (0.40)
Right knee flexion	1.70 (0.11)	1.55 (0.23)
Left knee extension	3.02 (0.47)	2.64 (0.41)
Left knee flexion	1.80 (0.18)	1.58 (0.33)
Trunk extension	5.52 (0.53)	5.12 (0.74)
Trunk flexion	4.11 (0.58)	3.21 (0.22)

Discussion

Anthropometry

Although the subject group was comprised of windsurfers from eastern and western countries, the standard deviation of the height measurement was 2.8 cm for the male athletes and 4.5 cm for the female athletes; for the weight measurement the standard deviation was 3.1 kg for the male and 3.6 kg for the female. Therefore, it seems that within each sex the subjects were similar in height and weight. Moreover, the mean values for the height and body weight measurement of the present male subjects were similar to those reported elsewhere. Allen and Locke (1) reported the height and weight for Australian elite windsurfers were 176.5 (± 1.72) cm and 67.1 (± 3.36) kg, and Plyley et al. (15) also noted that Canadian elite windsurfers were 172.3 cm in height and 65.7 kg in weight. All in all, it is reason to state that there is a need for the elite windsurfers to have a definite range in height and weight. It is because, as has been discussed by Allen and Locke (1), the windsurfers have to have an optimal weight in order to balance the frictional force and the countering force to the wind. Both of these two forces increase proportionally with the body weight but the increasing of frictional force will slow down the board speed, while the increase of countering force to the wind will improve the board speed especially under high wind condition. For the body height measurement, the athletes have to balance and be agile on the board which will be hindered by having a tall stature, and the capacity to counterbalance the rig via leaning into the wind to provide control of the sail and the board.

In body fat measurement, the male subjects displayed a relatively low value (6.8 ±2.2 %) in comparison of the Canadian Windsurfing Team (14.3 %) (15). Allen and Locke (1) stated that the skinfold sums of their windsurfers exceeded those reported for the athletes in cycling, gymnastics, hockey, kayaking, rowing, skiing, swimming and track and field. But the male subjects in this study possessed a body fat level which appears to be lower than that of Canadian Olympic Soccer players (9.8%) (18) and Australian Soccer players (9.7%) (26). Such differences in body fat content between this study and the past studies may reveal the fact that the physical stress on windsurfing has been increased dramatically in the past few years. The body fat content of the present subjects fell in the range of runners (25) which are 6.3-7.5 % for the male runners and 15.2-19.2 % for the female runners. Therefore, it is reasonable to assume that the physical demand on the windsurfers is similar to that on runners. Moreover, as the present subjects didn't change in body weight as in comparison with past studies as indicated above, but with the drop in body fat content, therefore, the windsurfers in this study had increased in their lean body mass, may be mostly from muscle mass, as in comparison with the windsurfers several years ago.

Pulmonary Function

All pulmonary function variables measured in this study were above normal value for the age group of the Hong Kong Chinese (18). In comparison with some other male elite athletes, the present male subjects had lower results than elite distance runners (FVC=5.88±0.56 l ; FEV_1=4.80±0.7 l; MVV=190+37 l/min) (11) and English soccer league players (FVC=5.8±0.2 l;FEV_1=4.95±0.2 l) (17). Such comparison indicated that windsurfing training would enhance the lung function capacity of the athletes but not up to the extent of endurance oriented and ball games training.

Cardiorespiratory Fitness

The relative VO_{2max} of the present elite windsurfers for both sexes exceeded those of untrained Canadian people (13), approximated those of elite athletes in basketball, ice-hockey (13), soccer (male subjects) (14), and was lower than endurance athletes, such as cross-country skiing, orienteering, modern pentathlon (16), distance running and rowing (13). As it is well accepted that the relative importance of the aerobic mechanism for the performance of any particular activity would be reflected in the position of elite players on the aerobic power (VO_{2max}) spectrum. On comparison, windsurfing do not make demands the aerobic power system as with the endurance type sports but similar to the team game sports with continuous work out and dispersed with intensive interval sprinting. Therefore, it is reasonable to suggests that a reasonably elevated aerobic capacity is a factor in elite windsurfing performance.

Flexibility and static hand grip strength

The flexibility of the hamstring was revealed by the sit-and-reach test. The result of this test as in comparison with other elite athletes in Hong Kong Sports Institute (24) (male : 30.4 (15.0-42.0) cm; female : 33.5 (18.0-43.6) cm) showed that the present subjects of both sexes had very good hamstring flexibility. It is well known that high levels of flexibility will increase the range of motion of the hip joints and prevent pulls and tears of the thigh muscles. This may be important for the modern windsurfing as pumping involve repetitive hip extension and flexion. For hand grip strength test, both the male and female subjects did not have statistically significant bilateral differences for this parameter. Therefore, it can be assumed that windsurfing demands both hands to the same extent. As the results of the hand grip test of the present subjects are higher than the other Hong Kong elite athletes (24) (male right hand : 45.1 (31.2-49.0) kg; male left hand : 43.5 (27.0-51.5) kg; female right hand : 33.1 (26.4-36.0) kg; female left hand : 30.9 (26.6-34.3) kg), the importance of grip strength to windsurfing is documented. Allen and Locke (1) noted that the windsurfers had to use the hands and arm in controlling the sail which make their grip strength higher than the sailors in other categories. But the handgrip strength of the present male subjects were lower than the hand grip strength of the elite Australian pre-Olympic windsurfing squad (Right : 57.4±2.1 kg; Left : 61.9±1.2 kg) but higher than a group of recreation and regatta windsurfers (20). The difference between the elite Australian pre-Olympic windsurfing squad and the present subjects might be due to the difference in the nature of the game. The Australian squad had to sustain griping the boom isometrically nearly for the whole course of racing but the present group had to work with the grip and wrist dynamically as pumping is employed unlimitedly during the race nowadays. These two modes of action may impose different stress on the grip strength capability of the subjects.

Anaerobic power

The anaerobic power data of the present windsurfers and a comparison with other Hong Kong and Australian elite athletes are presented in Table 6.

Table 6. Anaerobic power tests-comparative figures from Hong Kong and Australian team athletes

Sport	Sex	N	Alactic work index (j/kg)	Lactic work index (j/kg)
Windsurfing (present study)	M	5	115 (5)	289 (22)
Soccer (HK Team) (3)	M	24	103 (20)	298 (27)
Squash (HK Team) (4)	M	10	127 (17)	324 (29)
Squash (Australian State Team) (22)	M	7	118 (15)	318 (19)
Road cycling (Australian national team) (23)	M	17	151 (13)	N.A.
Swimming (Australian national team) (22)	M	63	118 (13)	299 (26)
Windsurfing (Present study)	F	5	105 (9)	261 (18)
Swimming (Australian national team) (22)	F	59	90 (11)	243 (23)
Squash (Australian State Team) (22)	F	7	86 (6)	241 (13)
Road cycling (24)	F	5	115 (3)	298 (11)

The alactic work index demonstrates an athlete's alactic work capacity, a requirement for sports involving short maximum efforts such as squash and badminton. The mean alactic work index of the male windsurfers was about the same as the squash players and swimmers, lower than cyclists, but appeared a be a bit higher than soccer players. For the female windsurfers, their results were higher than swimmers and squash players but lower than road cyclists. The lactic work index reveals how well the athlete can sustain a maximum power output over 30 seconds (lactic work capacity). The male windsurfers' results tended to be lower than the scores from all the reference sports, especially squash. For the female windsurfers, their results were lower than cycling but higher than swimming and squash. This may suggest that the elite windsurfers possess a good alactic work capacity in their lower body muscles as with other sports, except those sport which rely heavily on lower body muscles, i.e. cycling. This finding is conflicting with the results gathered by Allen and Locke (1). They found that their subjects' (Australian windsurfing team) leg alactic anaerobic power might not be well developed. Such difference may due to pumping. When the windsurfer pump the sail, the instant force generated by the movement of the sail will be transferred to the sail board through the lower body muscle group and therefore the lower body muscle should be powerful enough to ensure that all the force can transfer to the sail board. Similarly, their lactic work capacity (30 seconds all out effort) was well developed in windsurfing but may to a less extent than their alactic system because the male windsurfers scored the less in this parameter as in comparison with other reference sports. As pumping action is about one pump per second or less and continuously, therefore the stress on the muscle endurance system and the latic system was high. Hence, the anaerobic capacity, especially the alactic work capacity of the lower body muscles seem to be important for windsurfing.

Isokinetic strength

In order to reveal the importance of knee and trunk muscles to windsurfing, the peak torque output of the knee and trunk were assessed. As with other elite athletes in other sports (21), the mean peak torque output of the left and right knees did not have significant bilateral differences for both male and female windsurfers ($p>0.05$).

The knee and trunk extension and flexion peak torque data of the present windsurfers and a comparison with other elite athletes are presented in Table 7 and 8 respectively.

Table 7. Knee extension and flexion peak torque - comparative figures from other studies.

Sport	Sex	N	Knee extension (Nm/kg)	Knee flexion (Nm/kg)
Windsurfing (present study-right knee)	M	5	3.12 (0.39)	1.70 (0.11)
Cycling (Chinese National Team) (10)	M	10	3.12 (0.33)	1.74 (0.17)
Soccer (Chinese National Team) (10)	M	14	3.10 (0.33)	1.60 (0.19)
Cycling - Track (Australian National Squad) (23)	M	14	2.98 (0.42)	N.A.
Cycling - Road (Australian National Squad) (23)	M	17	2.56 (0.23)	N.A.
Squash (HK Team) (4)	M	10	3.11 (0.38)	1.87 (0.18)
Windsurfing (present study-right knee)	F	5	2.68 (0.40)	1.55 (0.23)
Badminton (24)	F	8	2.77 (0.44)	1.52 (0.19)
Basketball (24)	F	20	2.58 (0.26)	1.34 (0.14)
Squash (24)	F	6	2.80 (0.11)	1.41 (0.20)

From the comparison of the male subjects, the windsurfers' peak torque generation capability of their knee extensors and knee flexors are similar to other sports which demand heavily on their knee muscles. Such phenomenon was found in the comparison of the female subjects also. Therefore, well developed knee extensors and flexors are important for windsurfing. Habal (7) stated that knee injuries are usual in beginners and intermediate windsurfers, because they do not recognize the weakness points. Therefore, it is important for the windsurfers to have strong knee muscles for knee protection and force transference as has been discussed above.

Table 8. Trunk extension and flexion peak torque - comparative figures from Hong Kong team athletes.

Sport	Sex	N	Trunk extension (Nm/kg)	Trunk flexion (Nm/kg)
Windsurfing (present study) (27)	M	5	5.52 (0.53)	4.11 (0.58)
Cycling (HK Team)(27)	M	7	5.22 (0.77)	3.41 (0.38)
Badminton (HK Team)(27)	M	5	5.95 (0.61)	4.00 (0.29)
Rowing (HKTeam)(27)	M	7	5.43 (0.11)	4.00 (0.61)
Squash (HK Team)(27)	M	7	5.00 (1.36)	3.80 (0.55)
Windsurfing (present study)	F	5	5.12 (0.58)	3.21 (0.22)
Badminton (24)	F	10	4.66 (0.49)	3.24 (0.31)
Rowing (24)	F	5	5.60 (0.88)	3.33 (0.58)

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Part 2

The effect of fatigue windsurfing pumping on multi-joint kinematics and coordination

Introduction

It has been well awared that much greater demands have been placed on windsurfers due to the relatively recent changes in the rule of Olympic course sailing events (10). According to the new rules, athletes are allowed to pump continuously to aid progress. There is alternation of muscle utilization in pumping as fatigue occurs during the race but the significant effects of fatigue on the control and coordination during multijoint repetitive pumping has remained unexplored.

Parnianpour et al (8) documented that decreases in primary plane trunk motion at the end of a test in which subjects were asked to perform quick and accurate sagitally symmetric repetitive flexion and extension within a trunk dynamometer. At the same time, they observed that accessory plane motions increased. They concluded that increases in frontal and transverse trunk range of motion were due to an adaptation in the neuromuscular control system as a result of fatigue. This study indicated that adaptations in the motor control and coordination will be come in due to neuromuscular fatigue. Potvin (9) discovered that there was no significant decrease in trunk motion symmetry during unconstrained repetitive lifting tests. But there were increased peak spinal flexion which may due to adaptation to muscle fatigue.

Such adaptation changes under fatigue state were found in sports movement also. Elliot and Roberts (3) guided runners to maintain steady speed throughout a 3,000 m run, with film taken at four periods during the race. Data taken 100 m from the finish showed differences compared to those from the three other periods. These differences included a decreased stride length and increase stride rate, increase support time and decreased non-support time, a greater angle of the lower leg with the vertical at foot strike, a less extended hip at the end of support, and a greater forward lean of the trunk. Similarly, Cavanagh et al. (1) conducted fatiguing runs on the treadmill and reported an increase with fatigue in step length of 6 and 8 cm for two runners.

Nyland et al. (7) stated that fatigue may be related to lower extremity injury. They studied the relationship of fatigued run and rapid stop to ground reaction forces, lower extremity kinematics, and muscle activation in 19 female collegiate basketball and volleyball players. They concluded that during fatigue, biodynamic compensations in the mechanical properties of the knee extensor musculature may occur to enhance knee stability.

The objective of this study was to provide information concerning the changes in pumping kinematics as fatigue progress that occur during continuous pumping on a windsurfing simulator.

Methods

Subject group

Six members (male : N=3 and female : N=3) of Hong Kong National Windsurfing Team were involved in this study. Mean (s.d.) age, height, and weight were 22 (6) years for male and 21

(4) years for female, 174.7 (10.8) cm for male and 164.7 (3.8) cm for female, 69.3 (5.5) kg for male and 53.9 (5.0) kg for female, respectively. Before participation, they were cleared to participate after a physical screening by an orthopaedic surgeon and signed a informed consent.

Windsurfing pumping simulator

The windsurfing pumping simulator was specially designed in Hong Kong Sports Institute for the windsurfers to perform pumping action during "reaching" (fig. 1). The simulator includs a power head of Club Gy-Ro rowing machine (Gy-Ro Sport Limited, Brentford Middlelesex, UK) which is used to mimic wind resistance force acting on the boom. The power head of the Club Gy-Ro is raised by a wooden block which is measured 100 cm in height. Then the cable outlet of the power head is 165 cm above the ground. A wedge shaped block with the shorter edge close to the power head (width : 71 cm, length : 40 cm, height : 10 cm and 2 cm) is put in front of the power head with 110 cm apart. A mast foot is secured on the left corner of the short side. The rig consist of the bottom section of a two-piece mast and boom, which is secured to the wedge via the mast foot. The cable from the power head is tightened on one side of the boom and the subject gripped the other side. The attachment point of the cable on the boom is adjusted to allow the resistance go directly in front of the subject. The resistance load of the power head of the Gy-Ro power head is set at Level 7 and the current power level is displayed on the monitor panel.

Kinetic Analysis Instrumentation

Two time synchronized JVC GY-XITC 3-CCD Color Video Camera with S-VHS-C Recorders were used to video taping subject's pumping action. The two cameras were positioned approximately at right angles to one another and the windsurfing pumping simulator was centered at the intersect point of the two cameras with 4 m apart from each of the camera.

All the analysis were done only on the right side of the subjects. Peak 3D Motion Measurement System (Peak Performance Technologies Inc., Englewood, U.S.A.) to perform 3D motion analysis of the ankle, elbow, hip, knee, shoulder, waist (lumbar spine) and wrist joints. Figure 2 provides the joint angle definitions for clarity. Moreover, analysis of the hand and center of gravity of the subject (calculated by the Peak System) movement in horizontal and vertical dimension were done. The points selected for digitization were the approximate joint centers of rotation of the above joints of the body, which included wrist, elbow, shoulder (acromion process), waist (anterior superior iliac spine), hip (greater trochanter), knee and ankle, as well as the centre of their hand and feet. This 3-D camera system was calibrated with Peak calibration frame. As this is a 3- Dimension motion analysis, all the joint angle measurements were referring to the internal angle between two segments, except shoulder joint. The shoulder joint movement was describing by 2 projected joint angles analysis on sagital plane (shoulder extension and flexion) and frontal plane (shoulder abduction and adduction) as the shoulder joint has multiple degree of movement freedom.

Procedure

Every subject tried the windsurfing pumping simulator one day before the testing date for at least 15 minutes. On the testing date, each subject perform 15 minutes of general stretching and then followed by 10 minutes rowing on a rowing ergometer at their own comfort pace for warm up. Then they performed five minutes of pumping on the pumping simulator for familiarization. Every subject was told to only perform pumping in reaching style and then they performed three minutes maximal pumping continuously. Encouragement and feedback were given to the subject for maintaining correct technique and full effort. Every 30 seconds the power output registered in the Gy-Ro power head were recorded. Right after the termination of the pumping movement, blood sample (25 ul) was collected from the subject's ear lobe for lactate analysis (1500 Sport, YSI, Yellow Springs Instrument Co., Inc. Ohio, U.S.A.).

Two complete pumping cycles were selected at about the 5th and 170th second. The first cycle represented the unfatigued state condition while the last cycle represented the fatigued state condition. The selected cycles were digitized and analyzed for each subject. One complete pumping cycle was comprised by two phases, pull phase and push phase. The pull phase commenced when the hand was seen start to going towards the subject and continued until the hand start to move away from the subject. The push phase was defined as the time course for the hand start to move away from the subject and continued until the hand start to reverse its traveling direction.

Descriptive statistics, including means and standard deviations, were obtained for all variables. Paired, two tailed *t* tests were performed to evaluate the unfatigued vs. fatigued effects onjoints movement during pumping in reaching style. All the subjects (both sexes) were grouped together for the paired *t* test.

Kinematic data can give a quantitative descriptions of the change of the range of motion and angular speed of movement of a particular joint in the selected cycles, but they can not describe the change of movement pattern in the selected cycles. For example, delaying of the start of joint movement, from smooth movement pattern to fluttering pattern. Therefore, in addition to present and compare the conventional kinematic data, a method in which the movement pattern of a joint is expressed by the normalized angular position trajectory drawn against the normalized motion phase duration was used. The angular position of a joint was normalized linearly so that for example, the peak flexion of elbow equal to 0, and the elbow peak extension was equal to 1. The normalized position for any angle is determined by a linear interpolation of the raw and normalized positions. Similarly, for normalizing linearly the duration of the pulling phase, the moment of the start of motion equal to 0 and the moment of the termination of motion equal to 1. In order to compare the change of movement pattern of the two selected cycles. The two normalized angular position trajectory were plotted against (superimposed on) the normalized motion phase duration. Twenty one points (at 0%, 5%, 10%......95% and 100%) along the normalized motion phase duration were selected, the corresponding normalized angular positions of the two tracectories were subtracted and then squared. The sum of the square of the differences of the two normalized angular position trajectories from the 21 points would quantify the change of movement pattern of the joint investigated.

Results

The total work output after three minutes all out effort pumping exercise and lactate response right after the cessation of the test were listed in Table 1. The mean lactate response were 7.72 mM and 7.25 mM for male and female subjects respectively. Table 2 shows the results for individual variables comparing nonfatigue data from the first collection pumping cycle for each subject to the assumed fatigue data from the last collection pumping cycle. The results showed that there were decreasing of hand movement in terms of the range of motion (not statistically significant) and average speed in the pulling phase and the whole pumping cycle (statistically significant). As the hand was holding the boom and which was attaching to the sail, therefore the hand movement can represent the sail movement. Moreover, the range of motion of centre of mass of the subject was decreased significantly in the vertical direction.

Table 3 summarise the joints kinematic variables for the start cycle and end cycle. For all the joints analysed, wrist, ankle, elbow, shoulder extension and flexion movement and knee had dropped in their range of motion while only ankle had statistically significant ($p<0.05$) changes. In the analysis of the extent of movement of each joint in the pull phase, all the tested joints except hip joint decreased in the extent of extension, abduction for shoulder and plnatarflexion for ankle. On the other hand, the corresponding drop of flexion, adduction for shoulder and dorsiflexion for ankle were much less. Among all these changes of the extent of joint movement, only elbow peak extension movement got close to the significant level of dropping. All the tested joints dropped in their speed of movements in the pull phase and also in the whole cycle, except shoulder extension and flexion movement. In average, all the joints in the pull phase dropped by about 20.1% of the speed of movement, with the ankle, wrist and shoulder abduction and adduction movemnent had statistically significant dropped ($p<0.05$), while for the whole pumping cycle, it was in average dropped by 11.6 % of the speed of movement and only shoulder abduction and adduction movement had statistically significant dropped.

Table 4 lists the average of the sum of the square of the difference of the normalised angular position trajectory of the start and end pulling phases. According to the results the joint had the most affected movement pattern after fatigue pumping was the wrist, and then ankle and then lumbar spine and then shoulder and then knee and lastly the elbow.

As with the analysis of the sum of square of the difference of the start and the end normalised angular position trajectories, the wrist joint curves had much differences qualitatively than the other joints among all the subjects. Ankle joint was the second joint in terms of variance of the start and the end trajectories. There were no general trend could be drawn from the graph of these two joints as their trajectories were different for each individual. For the elbow and knee joints, the first and the end trajectories were almost the same with only one exception in one of the six knee joints assessed. For the hip and waist joints, more than half of the subjects had their hip and waist joints extend earlier and finished the flexing movement earlier after three minutes of pumping. Shoulder joints were flexing earlier by about 5-10% along the pulling phase.

Table 1. Total work output and after exercise lactate response of the subjects.

Subject	Sex	Lactate (mM)	Total Work (Units)
A	M	9.15	332
B	M	5.25	325
C	M	8.75	475
Mean	**M**	**7.72**	**377**
D	F	5.51	221
E	F	7.11	252
F	F	9.14	350
Mean	**F**	**7.25**	**274**

Table 2. The change of pumping kinematics across the period for continuous all-out pumping.

	Start		**End**		**P**
	X	**SD**	**X**	**SD**	
Hand					
Range of motion in pull cycle	58.7	9.3	51.7	9.3	.054(NS)
Average speed in pull cycle	106.5	29.6	87.9	21.3	.008(Sig)
Average speed in whole cycle	105.8	31.3	94.0	25.0	.046(Sig)
Centre of gravity of the subject in horizontal					
Range of motion in pull cycle	17.5	4.3	18.3	2.6	.485(NS)
Average speed in pull cycle	53.6	15.1	45.3	4.7	.138(NS)
Average speed in whole cycle	36.7	11.3	33.3	6.7	.240(NS)
Centre of gravity of the subject in vertical direction					
Range of motion in pull cycle	17.7	4.5	14.0	2.0	.032(Sig)
Duration in pulling cycle	0.61	0.13	0.64	0.12	.341(NS)
Duration in whole cycle	1.11	0.18	1.13	0.20	.505(NS)

Sig : statistically significant ($p<0.05$)
NS : statistically non-significant ($p>0.05$)

Table 3. **Summary of the values of the first and last pumping cycle to indicate the effect of fatigue on kinematics changes of the elbow, shoulder, knee, ankle, wrist, hip and lumbar spine.**

	Start		**End**		**P**
	X	**SD**	**X**	**SD**	
Range of motion (degrees)					
Ankle	13.4	5.3	9.6	2.3	.048(Sig)
Elbow	114.8	12.6	109.1	10.0	.212(NS)
Hip	54.5	13.1	56.6	8.8	.706(NS)
Knee	46.6	16.5	39.8	7.8	.227(NS)
Shoulder - Saggital plane	144.3	14.2	145.4	10.1	.821(NS)
Shoulder - Fronatl plane	112.6	34.3	84.0	14.0	.062(NS)
Lumbar spine	28.5	8.1	27.1	4.6	.648(NS)
Wrist	26.0	7.8	20.9	8.1	.089(NS)
Pull Cycle - Maximum angle attained (degrees)					
Ankle-Plantar flexion	130.6	11.2	123.1	15.2	.153(NS)
Elbow-Extension	173.1	3.0	170.3	3.8	.066(NS)
Hip-Extension	175.7	2.4	176.7	1.5	.487(NS)
Knee-Extension	163.4	5.0	157.4	13.7	.203(NS)
Shoulder-Saggital plane-Extension	119.4	11.6	117.9	13.1	.631(NS)
Shoulder-Fronatl plane-Abduction	134.6	32.2	108.0	18.5	.122(NS)
Waist-Extension	174.7	3.0	172.2	4.8	.162(NS)
Wrist-Extension	174.2	2.5	171.6	7.7	.406(NS)
Pull Cycle - Minimum angle attained (degrees)					
Ankle-Dorsiflexion	117.2	9.9	113.5	15.6	.427(NS)
Elbow-Fexion	58.2	15.3	61.2	9.4	.486(NS)
Hip-Flexion	121.2	12.8	120.1	8.2	.816(NS)
Knee-Flexion	116.8	16.1	117.6	15.7	.897(NS)
Shoulder-Saggital plane-Flexion	24.8	15.9	27.6	14.9	.613(NS)
Shoulder-Fronatl plane-Adduction	22.1	15.6	24.1	19.0	.711(NS)
Waist-Flexion	146.2	7.8	145.1	3.1	.734(NS)
WristFlexion	148.1	9.4	150.7	13.8	.483(NS)
Average angular speed (deg/sec)					
Pull Cycle					
Ankle	41.6	22.5	25.5	11.0	.027(Sig)

Elbow	206.0	37.2	184.1	25.9	.111(NS)
Hip	112.0	33.9	102.4	15.6	.430(NS)
Knee	96.9	44.7	75.2	27.7	.074(NS)
Shoulder - Saggital	258.1	67.0	238.8	44.4	.232(NS)
Shoulder - Frontal	235.4	81.7	160.5	33.3	.021(Sig)
Waist	77.3	26.7	64.9	24.0	.229(NS)
Wrist	110.7	43.4	82.8	37.7	.021(Sig)
Whole Cycle					
Ankle	33.4	13.7	27.5	9.4	.226(NS)
Elbow	204.7	15.6	196.5	26.8	.423(NS)
Hip	110.5	24.6	107.5	15.5	.752(NS)
Knee	88.8	39.2	71.1	22.3	.151(NS)
Shoulder - Saggital	253.4	59.1	254.1	55.5	.961(NS)
Shoulder - Frontal	231.8	83.5	166.6	30.6	.031(Sig)
Waist	72.0	27.1	68.3	24.4	.526(NS)
Wrist	91.4	31.6	87.8	41.5	.684(NS)

Sig : statistically significant ($p<0.05$)
NS : statistically non-significant ($p>0.05$)

Table 4 : The average of sum of the square of the differences of the start and the end pulling phase normalised angular position trajectories.

	Elbow	**Hip**	**Knee**	**Shoulder -Saggital**	**Shoulder-Frontal**	**Wrist**	**Waist**	**Ankle**
Average	0.06	0.33	0.16	0.07	0.72	2.95	0.89	2.27
S.D.	0.04	0.31	0.14	0.07	0.94	1.30	0.56	2.62

Discussion

The results of their investigation suggested that several kinematics variable were altered during maximally pumping for three minutes.

Although there is no direct method of measurement of energy expenditure in this study, the vertical excursion of the body centre of mass, which was estimated using the video joint kinematics and body segment parameters, was significantly less ($p<0.05$) at the end. Hence, it is inferred that less energy was spent in raising the body against gravity. Moreover, the boom movement, indicated by hand movement, was decreased significantly at the end of 3 minutes pumping in terms of pulling speed and range of motion. This showed that less energy was available to oppose the tension of the Pumping Ergometer Head. All there could relate to the fact that the energy output from the windsurfers had decreased significantly and they could be assumed to have reached the fatigue point. Moreover, their high lactate

(7.48mM ±1.79mM) response after the pumping exercise also indicated that their skeletal muscle had reached the fatigue stage (4-6.)

Although there sere dropping in the range of motion for all the tested joints, none of them reached statistically significant level, except ankle joint. This may indicated that it is important to maintain the range of motion of all the joints in the body in order to maintain the speed and range of motion of the hand (the sail). Hence, to maintain the generation of wind force from the sail. The joints movement involved small muscle groups showed significant level or close to significant level of dropping in the range of motion and we may assume that these muscle groups were fatigue the most in comparison with other muscle groups. Therefore, these small muscle groups, ankle plantar flexors and dorsiflexors, mid-deltoid as well as wrist extensor and flexor have to be trained more. Moreover, all the extensors of the tested joints, abductor of the shoulder and plantar flexor of the ankle are stressed highly, as their drop in the maximum angle attained were decreasing more than their respective antagonistic muscle groups.

As the speed of movement dropped more in the pulling phase than measured in the whole cycle, it may due to the fact that the subjects tended to rest longer in the pushing phase as they fatigue and results in keeping the speed of movement measured in the whole cycle about the same for the working time.

Before fatigue, the pulling is started by the extending of the hip joint and lumbar spine and flexing of shoulder joint. The hip joint as well as waist complete their extension at around 60-80% of the pull phase duration, and the shoulder joint terminate the abduction motion at around 70-90% of the pulling phase duration. At around 30-40% of the pull phase duration, the elbow joint flex and the pull phase duration, the elbow joint flex and the knee joint extend to finish the pulling phase.

It is assumed that goal directed movement (in this case, pumping action) is completed by an ideal sequence of co-ordination (2). Therefore departure from this pattern indicates a change in co-ordination.

Conclusion

Three minutes of pumping on the windsurfing pumping simulator evoked fatigue feeling on the subjects. In the fatigue state, the windsurfers will try to maintain the sail movement speed and range. It would appear that: 1) in the pumping action, the brachioradialis was fatigued the most, and 2) after 3 minutes of pumping, a drop in the ankle movement reflects a drop in the lower body muscles power.

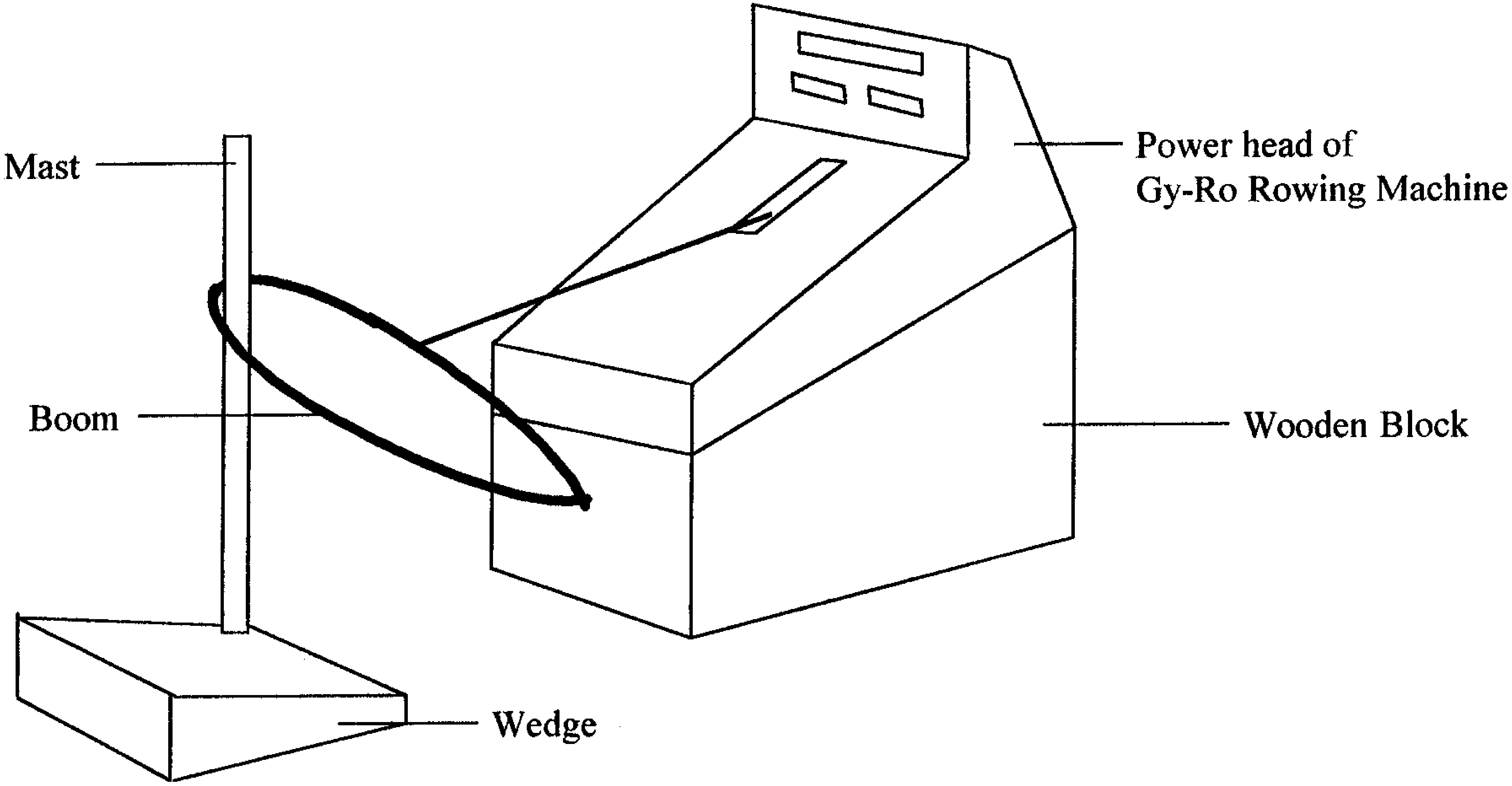
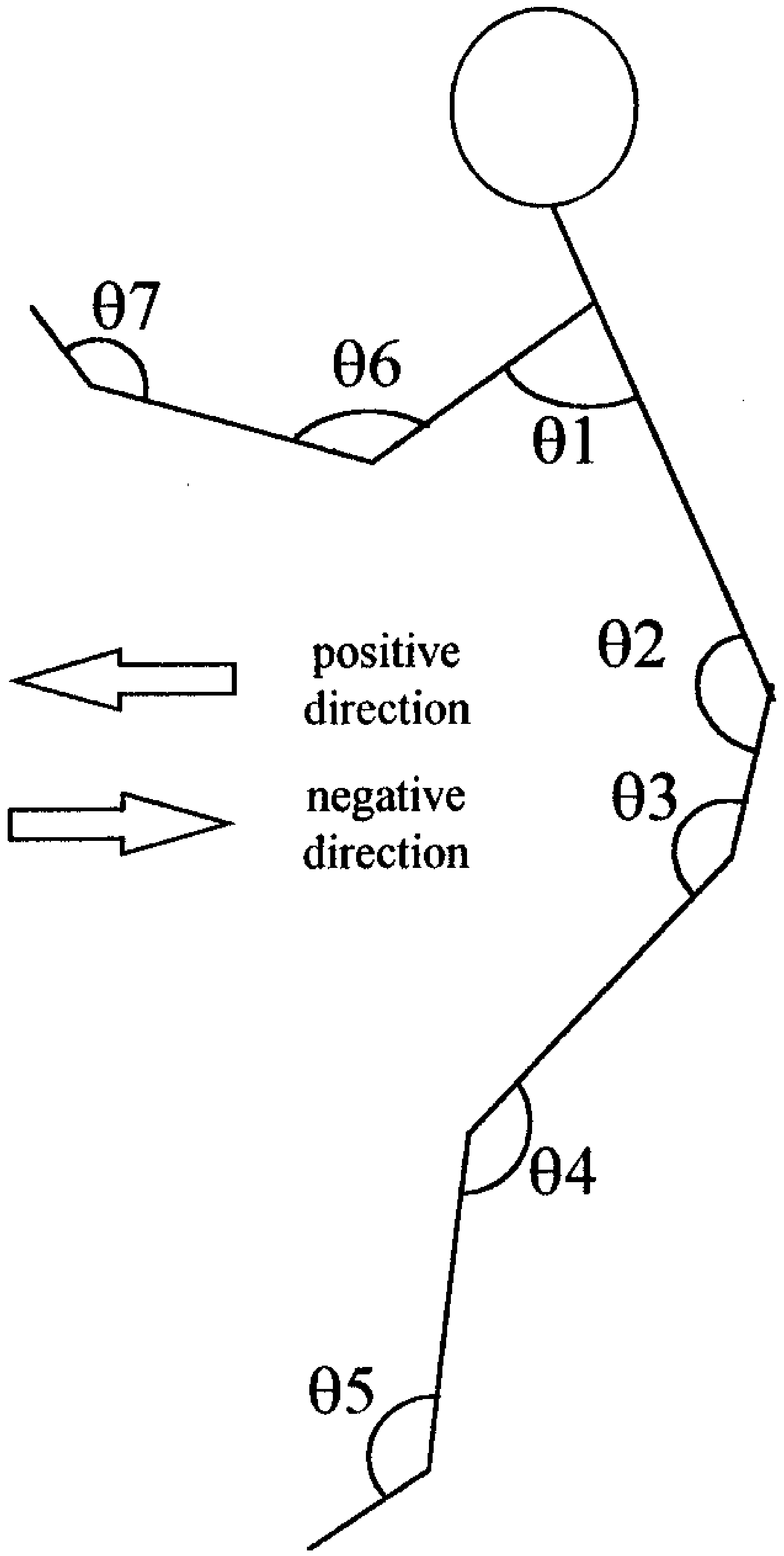


Fig 1. Windsurfing Pumping Simulator.



JOINTS

θ1	Shoulder Extension
θ2	Waist
θ3	Hip
θ4	Knee
θ5	Ankle
θ6	Shoulder
θ7	Wrist

Fig 2. Definition of the joint angles for the kinematic and co-ordination measures.

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Part 3 & 4

Assessment of muscle fatigue in windsurfing pumping by surface EMG

Introduction

Since 1992, windsurfing involves highly repetitive dynamic contractions, pumping which is one of the determinate factors in windsurfing performance. The board speed will be increased by pumping therefore, if the athlete can pump longer, he or she can finish the course in a shorter time. During the race, athletes tend to slow down or stop the pumping action, because of muscle fatigue.

Information about muscular activity during windsurfing is scarce. In the early days, as pumping was limited to three pumps per wave, studies were confined to static conditions. An electromyographic study of windsurfers with different skill levels was conducted to identify the most important muscles of the body in various standard surf-postures (7). Surf-posture refers to standing on the surf board with hands on the boom. The study found that all muscles display rather low activity (an average of less than 20% of their maximal isometric values). Windsurfing did not seem to be very demanding in terms of muscular force. But today, pumping is an integral part of racing. Therefore, the muscle activation pattern may be completely different. Recently, Buchanan et al. (1) and Dysan et al. (4) had examined the responses of the windsurfers during laboratory-based simulation tasks and on the open water respectively. Electromyographic activity of the windsurfers was recorded. Both of them indicated that during pumping upwind and reaching, muscular activity of the arm was the greatest in comparison with the shoulder and leg. Moreover, Buchanan et al. (1) found that electromyographic activity during dynamic condition was higher than that reported previously during simulation with isometric work.

However, the muscle registered with the highest electromyographic activity level may not be the muscle fatigue the most during continuous work out at that specific movement. Muscle fatigue may be the most significant factor for the slowing down of pumping action. There is a need to identify which muscle group fatigue the most during pumping. If these muscle groups can be identified, the muscle training program can be planned accordingly.

Currently, spectral alternations of the EMG signal have been used in studying of muscle fatigue. Under isometric conditions, the correlation of muscle fatigue and shift of the power spectrum towards lower frequencies are well documented (3). But the work on assessing EMG spectral changes under dynamic situation is limited. Gerald et al. (5) investigated the mechanical performance, EMG activity, perception of fatigue and their relationships during repeated isokinetic shoulder flexion performed with maximal effort. They concluded that the changes in the mean power frequency, for one muscle or several muscles together, were parallel with the mechanical fatigue. Several more studies concerning repeated maximum dynamic contractions of the shoulder flexors and the plantar flexors have demonstrated steep parallel decrease in mechanical performance and Mean Power Frequency (MPF) of the muscles under investigation during the initial 40-70 contractions (the fatigue phase) followed by stable levels (the endurance phase), during more than 100 remaining contractions (5,6).

Although EMG frequency shift has been described under isokinetic contractions, work on ergometer was not well documented. It is ideal to obtain a quantitative index of muscular fatigue through evaluating the shift of frequency spectrum towards the lower frequencies under dynamic work on the specific ergometers for different sports.

The first part of the present study was to investigate the relationship between EMG frequency components and the work output during maximal voluntary isokinetic knee extensions and elbow flexion. Subjects under investigation included untrained subjects, windsurfers and rowers.

The second part of the study was to repeat the investigation on windsurfers during maximal pumping actions on a windsurfing pumping simulator.

PROCEDURE

Part 1.

Eight male normal subjects with average age, weight and height as 21±2 years, 61.2±3 kg and 169±5 cm participate this study.

One week before the test, every subjects had one session to come to the Human Performance Laboratory of Hong Kong Sports Institute to accustom to the testing procedures and tried on the isokinetic loading dynamometer Cybex 6000 (Cybex Corporation, RonKoKoma,NY).

According to the manufacture recommendation, torque and angle calibration was done before each test session.

a) Test movement

Every subjects have to perform two movement tests, they were knee extension, and elbow flexion.

b) Test speeds and repetition

Test in each movement test was done at one speed-180 deg/sec. For knee extension, 50 repetitions were performed while for elbow flexion 40 repetitions were performed.

After obtaining informed consent, the subjects' weight and height were measured. A 10-minutes general stretching and warm up was performed to prepare the muscles for each test movement. T-shirt and shorts were required, shoes were removed for the knee extension test.

After setting the apparatus for the appropriate joint movement, the subject was stabilized with straps to the testing apparatus. The two movement tests settings were adjusted according to Cybex 6000 Testing and Rehabilitation System-User Guide. For knee extension, the subject sat on the dynamometer chair and stabilized by thigh, hip and chest straps. For elbow flexion, the subject lied on the U.B.X.T. (upper body exercise table) in supine position. His/her right arm abducted to an angle about 45° from the body . The subject body was fixed with straps on their hips and chests. For each joint movement, the joint axis of rotation was aligned with the input shaft of the dynamometer. All adjustments were made by the same investigator.

Then the subject underwent a warm up session at 180 deg/sec for 5 repetitions in order to get used to the test speed. After the warm up session, subjects were instructed to perform muscle actions continuously with maximal effort through the entire range of motion.

For capturing EMG, two Ag-Ag/Cl surface electrodes (1.5cm in diameter-the gel surface; Marquette, Jupiter, FL, USA) were placed 4 cm apart on the geometric middle of the muscle belly under contraction, with their detection surface along the length of the muscle fibers of Retus Femoris and Biceps Brachii, for knee extension and elbow flexion respectively (2). A ground electrode (15 cm in diameter - the gel surface; Marquette) was attached on the ankle. The skin was prepared to reduce skin impedance before application by rubbing with alcohol and ether (4:1) and then skin abrasion.

Part 2.

Windsurfing Pumping Simulator:

As described before. "The effect of fatigue windsurfing pumping on multi-joint kinematics and coordination."

Test Procedures :

Each subject warmed up for 10 min on the windsurfing pumping simulator to familiarize himself or herself with the equipment and to practice the technique. The subjects were instructed to assimilate the pumping action in reaching style on the simulator. Each testing session lasted 3 minutes and during the test the subjects were given verbal encouragement to maintain the correct technique and produce their best efforts.

Raw EMG and HR were recorded continuously for the whole test period. The power output, read from the power head of the Gy-Ro rowing machine were recorded every 30 second, i.e. totally 6 data were recorded.

Analysis :

EMG data was analysis by Lab-View ^{R} to resolve the mean power frequency of the captured EMG in each muscle contraction cycle.

Results and Discussion

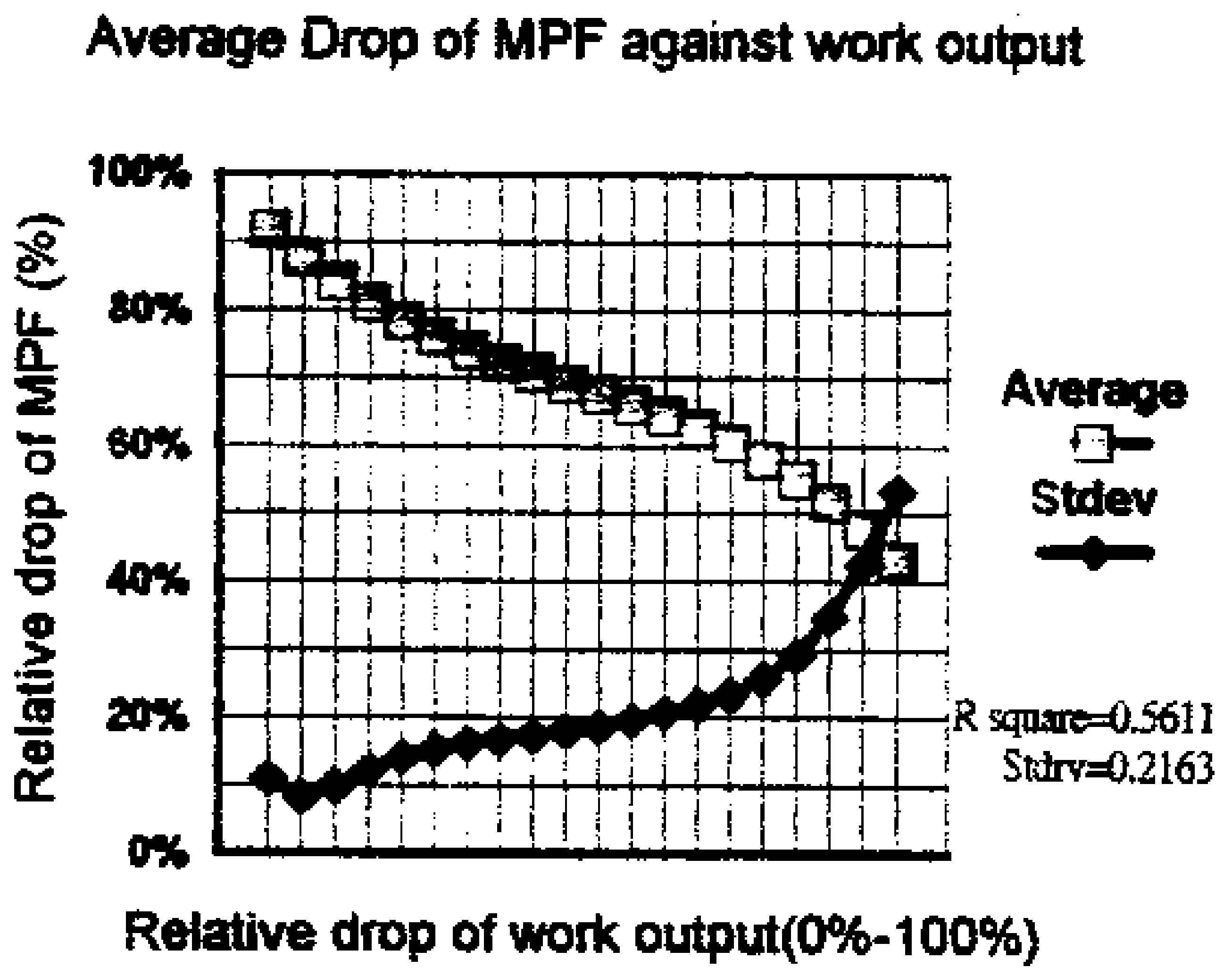
Multiple Regression method was used to analyze the relationship between the drop of the mean power frequency (MPF) of the elbow flexor (biceps and brachioradialis) and knee extensor (Rectus Femoris and Vastus Lateralis) and the drop of their work output during Cybex muscle fatigue test. The average R square value of the subjects was around 0.6 and this suggested that there is a statistically significant correlation between the drop of MPF and the drop of work output from the same muscle group. The average drop of the MPF and the work output were plotted for each muscle and listed below.

From the graphs, it can noted that the standard deviation of the average relative MPF of each muscle was quite constant from 0 % to 60 % of relative drop of work output from the respective muscle. Beyond 60 % of relative drop of work output, the respective standard deviation of the MPF was rising sharply and getting close to or even higher than the average MPF. Therefore, it can be assumed that as the relative work output of a particular muscle dropped over 60 %, the drop of MPF can't account for the drop of work output. But before, 60 % drop of relative work output, the drop of MPF can account for the drop of relative work output.

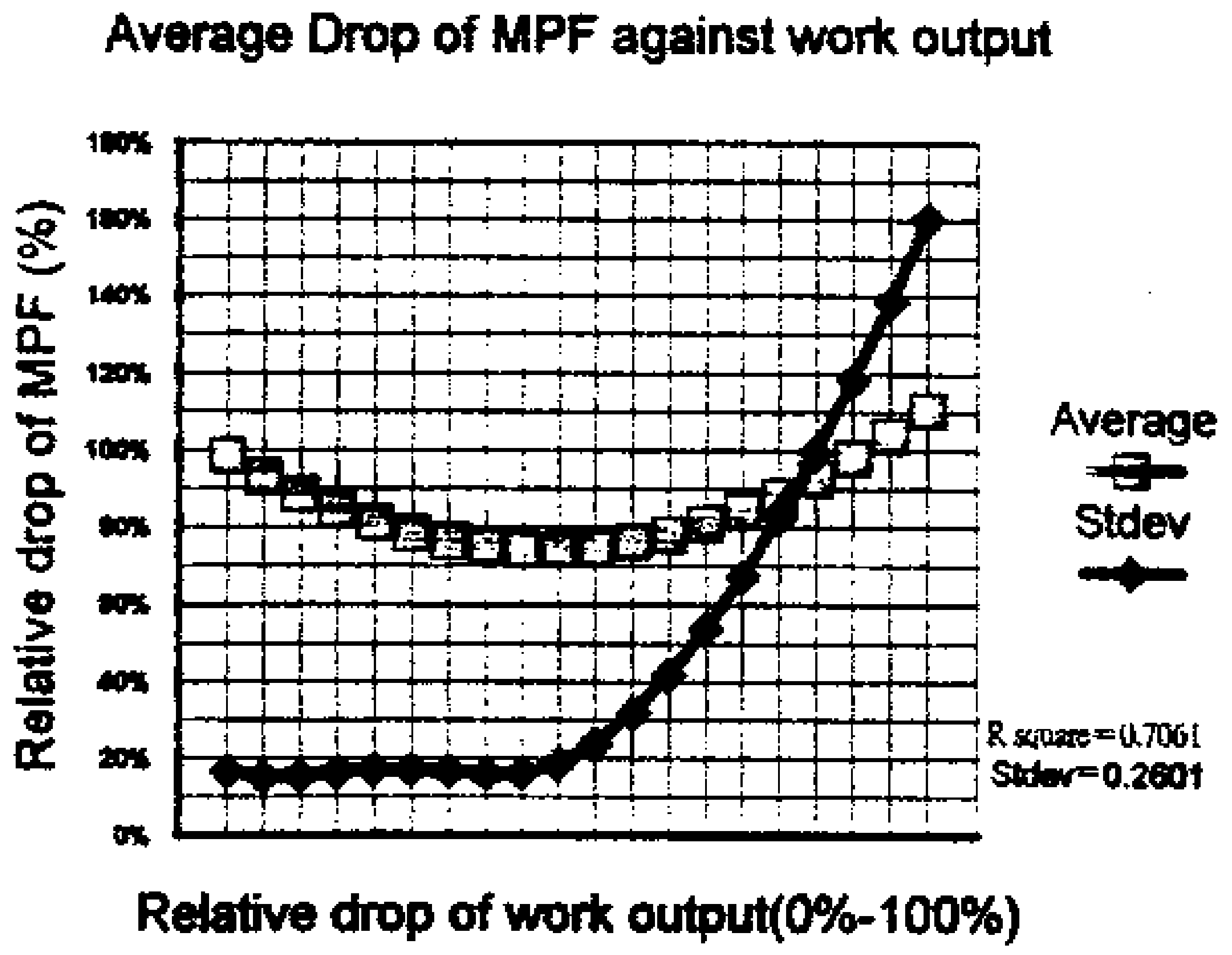
As from Part B of this report had demonstrated that three minutes continuos pumping (reaching style) on the windsurfing pumping simulator can fatigue the subject, the analysis of the MPF of the eight muscle groups from the two windsurfers when they performed three minutes continuos pumping can reveal the fatigue pattern of each muscle group. From the graphs, the MPF of each muscle group show rise and drop which demonstrate that this muscle group is working and stressed and then fatigue, and after a while reactivate again. As one muscle group drop in its MPF, there will be another muscle group has its MPF rise. This may indicate that there is a compensation coordination among the muscle groups. As one muscle fatigue and need rest, another muscle group may work more to take up the work of the fatigue muscle. Once the fatigue has got enough rest, may be 10 or 15 seconds, it may reactivate again.

For the result of the top windsurfers:

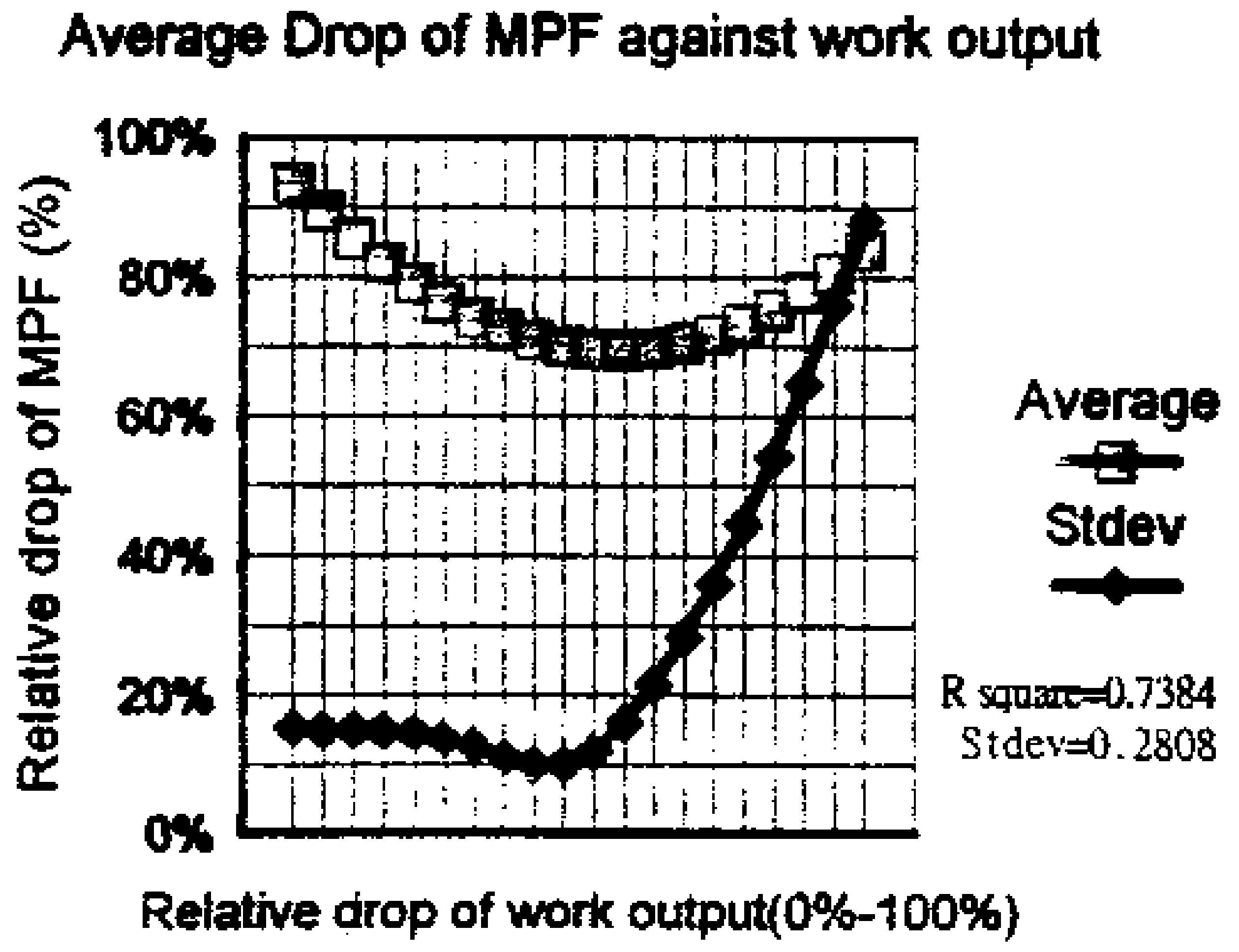
When the muscle fatigue patterns of the two windsurfers were compared, they were found to be different. This suggested that the two windsurfers employed different muscle activity patterns for this task. Windsurfer 1 involved all muscles at the start of the pumping action and gradually built up to maximum work output at about the end of the second minute. After that, all the measured muscles showed evidence of fatigue. Windsurfer 2 activated muscles in rotation. All muscles were activated at the first 30 seconds, then, at the second 30 seconds, all muscles, except brachioradialis and quadriceps, went into a less active state. At the third 30 seconds, the brachioradialis went into almost complete rest while the quadricpes worked for another 30 seconds more. During the drop of brachioradialis activity, the mid-deltoid increased its involvement to maintain power output for 30 seconds. It then rested for 30 seconds before continuing for another 30 seconds when the 3 minute pumping action task was terminated. The back muscles were more involved at the latter half of the pumping movement.



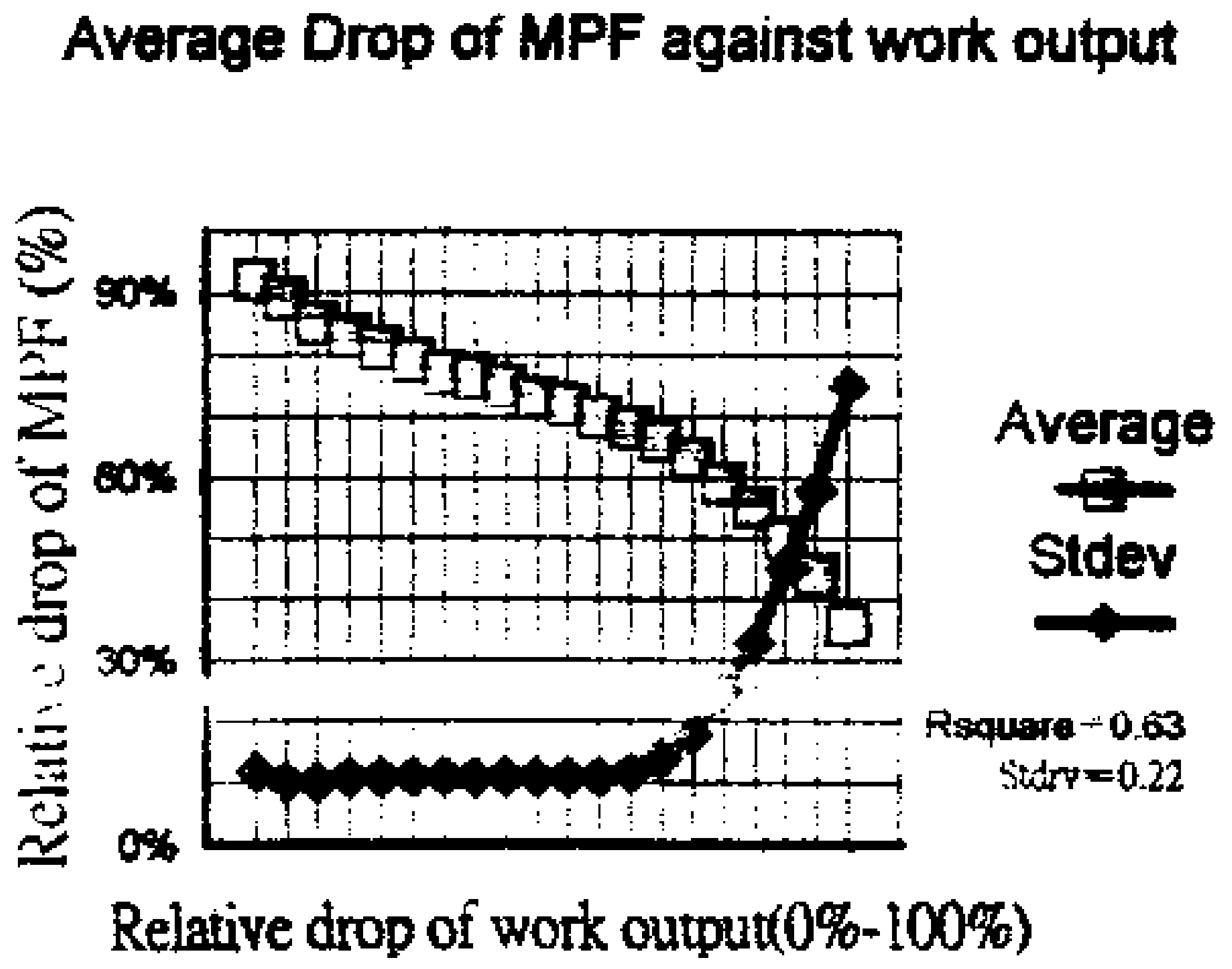
Brachioradialis



Biceps

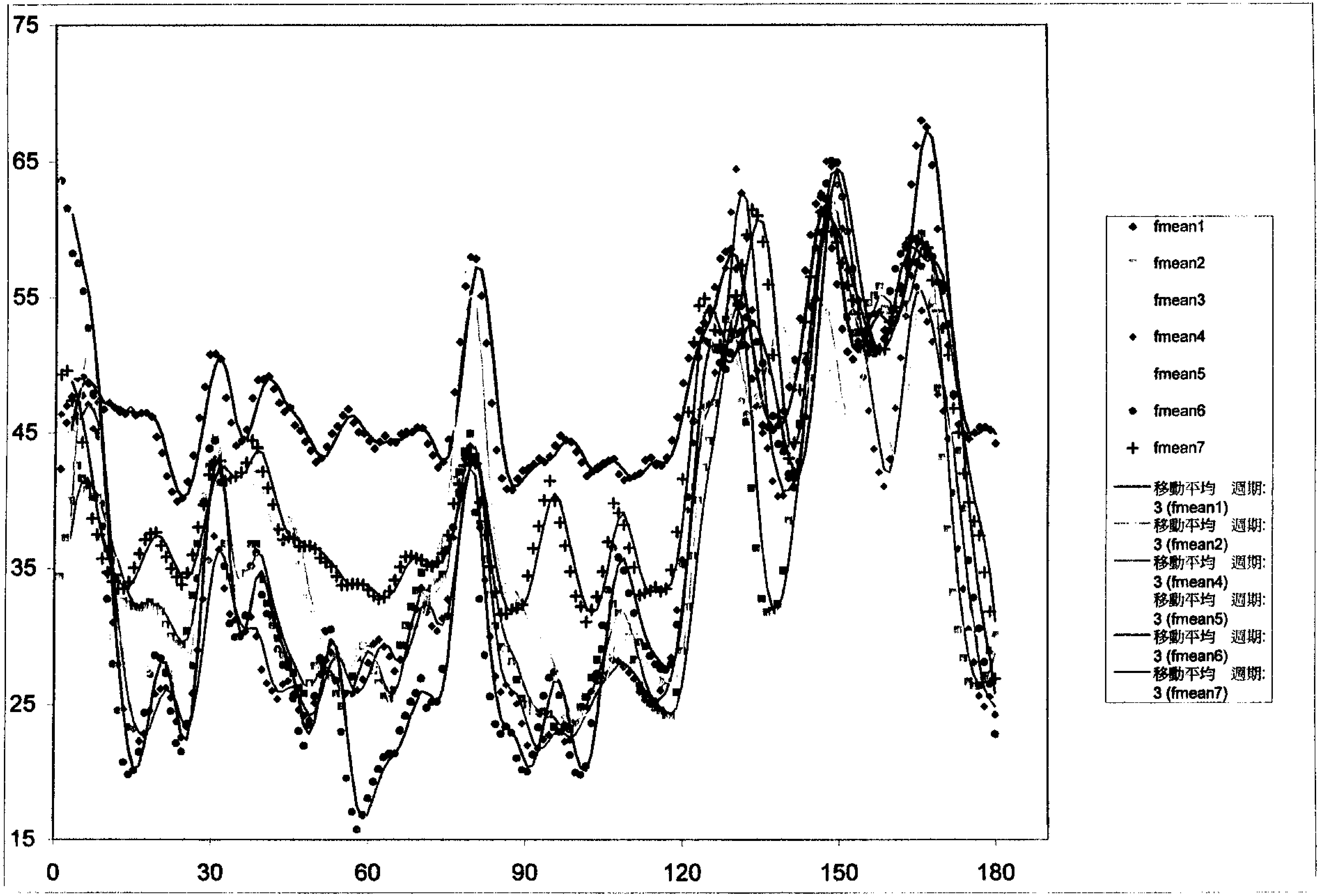


Vastus Lateralis

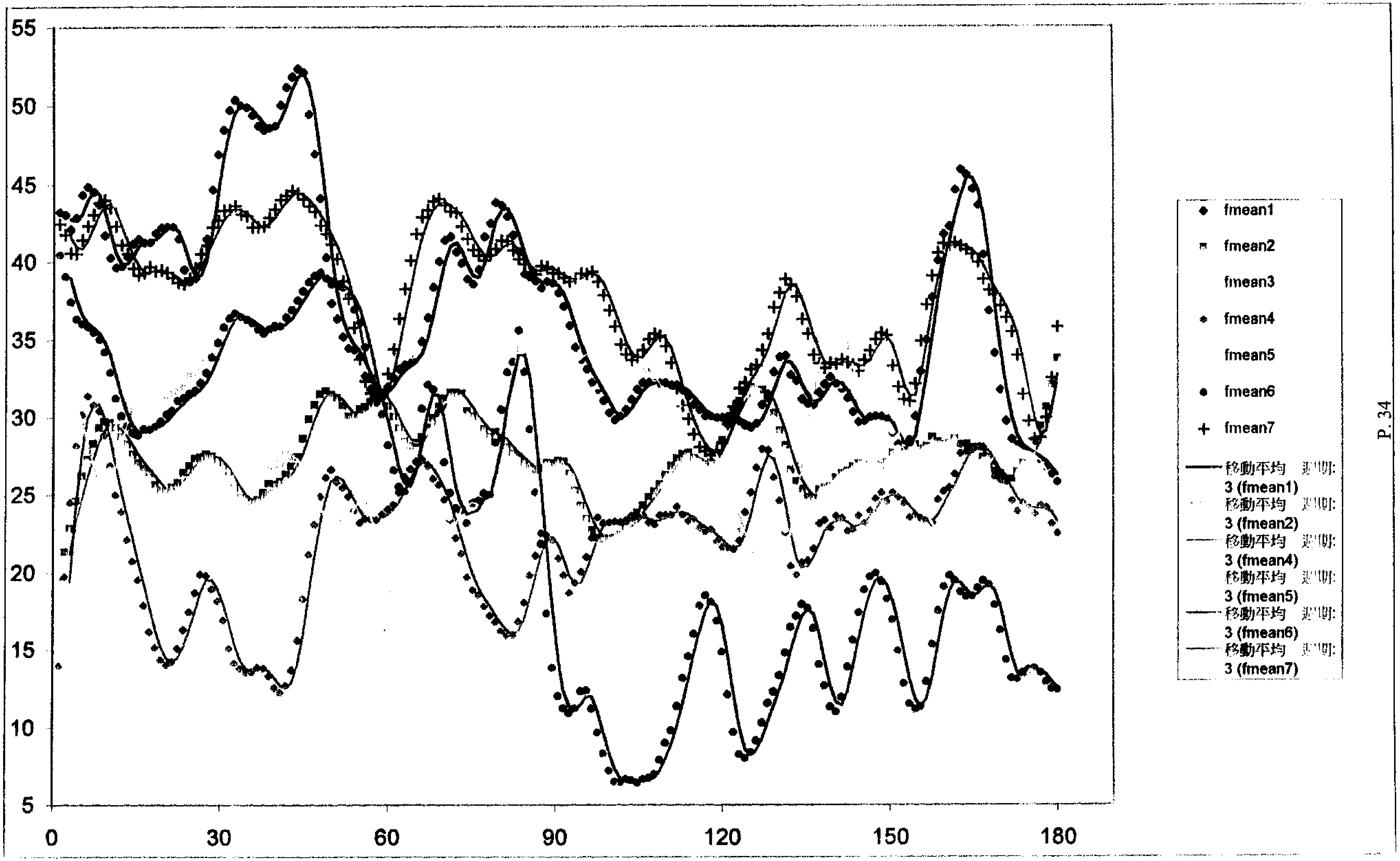


Rectus Femoris

Windsurfing 2 pump 3min (1 set)



Windsurfing 1 pump 3 min



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