Fatigue analysis in Sports Activities – Application in performance and injury prevention

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Muscle strength and sport injury

- **Kibler et al. (1988)** recommended flexibility and strength training for tennis players at frequent level.
  - As shoulder weakness was found to be correlated with the increase of injury.
- **Stafford and Grana (1984)** echoed that muscular weakness and decreased flexibility cause biomechanical imbalances which often result in dysfunction and pain.

Muscle strength and sport injury

- **Jobe & Jobe (1983)** noted that muscular performance is important in the prevent and treatment of muscle dysfunction and pain
- Strength and **strength ratios**
- Strength imbalance exceeding 20 lbs between dorsi- & plantarflexors-goes with people with shin splints **(Gleim et al., 1978)**

Isokinetic profile of dorsiflexors and planta flexors of the ankle-a comparative study of elite versus untrainined subjects

So, R., Siu, T.O., Chan, K.M., Chin M.K.
British Journal of Sports Medicine 1994 28(1):25-30

- Sports that involve more jumping and running require higher plantar flexion to dorsiflexion torque ratio to stabilize the ankle.

Sport activities

One bout vs. Continuous

Fatigue – muscle

- Fatigue by definition is an “exercise induced reduction in maximal voluntary muscle force” **(Gandevia 2001)**

- Muscle endurance, which is the time period for which a constant (non-fatiguing) force output can be maintained. **(Bigland-Ritchie & Woods 1984)**

Muscle fatigue impact in sport:

- Reduce motor performance and hamper motor control - Increase the energy cost of performing exercise **(Lepers et al. 2002)**

- Muscle activation patterns and kinematics were altered - Increase the injury risk. **(Brereton & McGill 1999)**

Chapman et al. (1990)

Goal directed movement is completed

by an ideal sequence of co-orduation

Muscle fatigue and sport injury

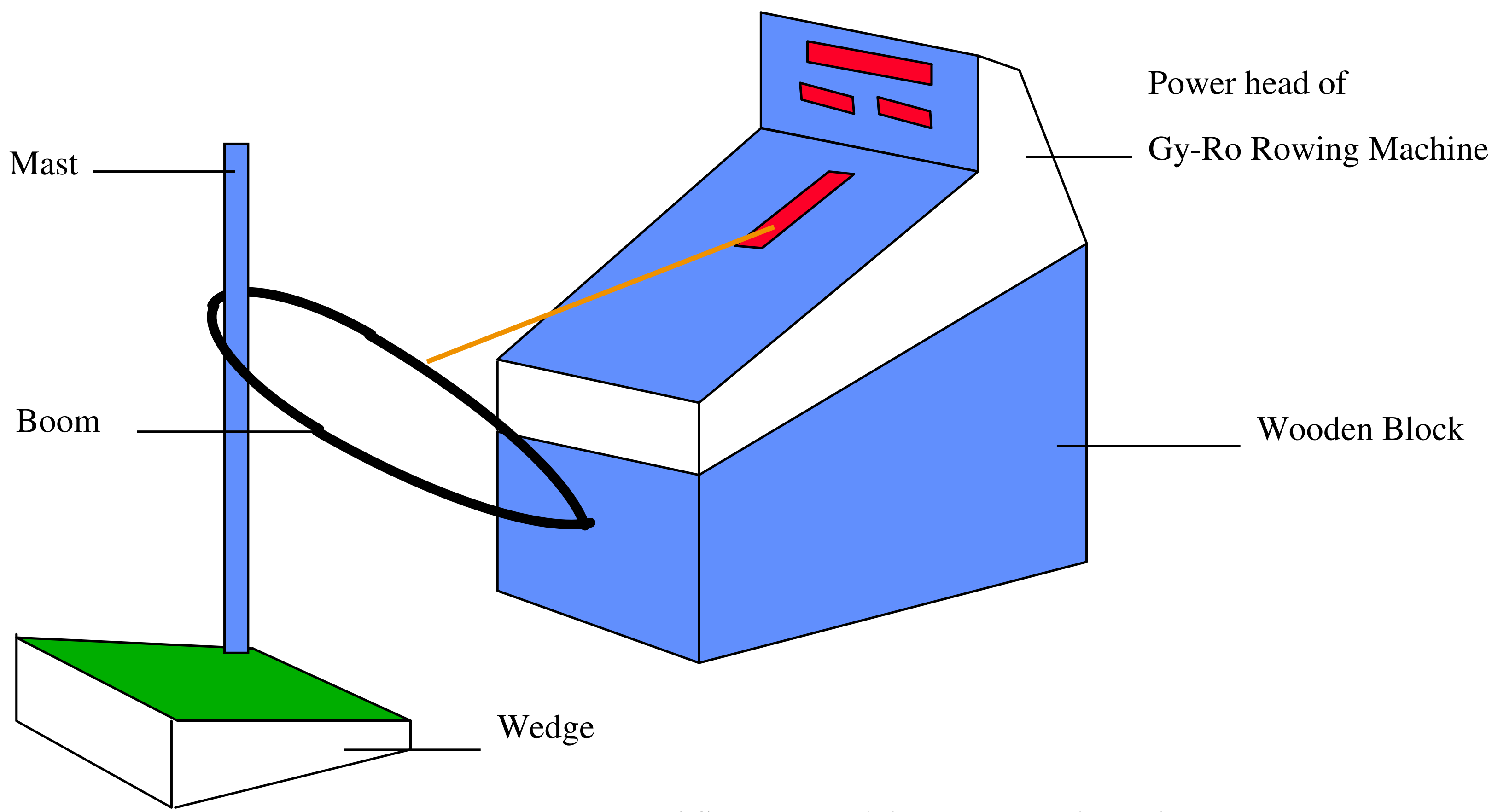
- **Van Deen et al. (1996)** noted that repetitive lifting induced a change in the postures, that was the fatigued subjects approached more and more pure back technique during lifting, in which the excursion of the body centre of mass decreased.

Bonato (2002)

- There is growing scientific evidence supporting the likelihood that back muscle fatigue leads to a loss of trunk muscle coordination, and to a progressive involvement (i.e., stress) of passive tissues of the spine. These effects may increase the risk of back injuries.

Changes in the multi-joint kinematics and co-ordination after repetitive windsurfing pumping task

So, R., Chan, K.M., Appel, R., Yuan, Y.



The Journal of Sports Medicine and Physical Fitness, 2004;44:249-57

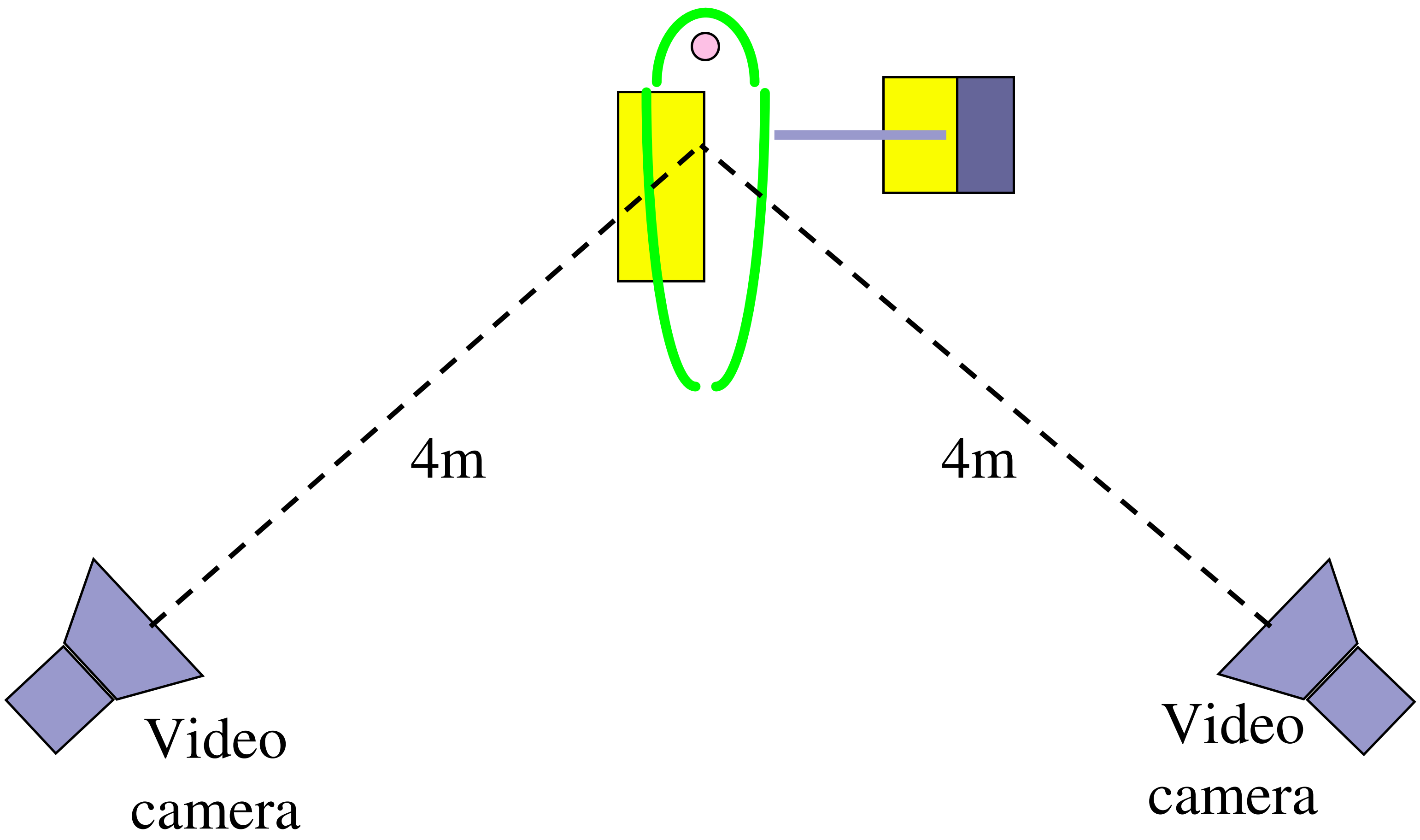
PUMPING - DURING START

PUMPING COMPETITION

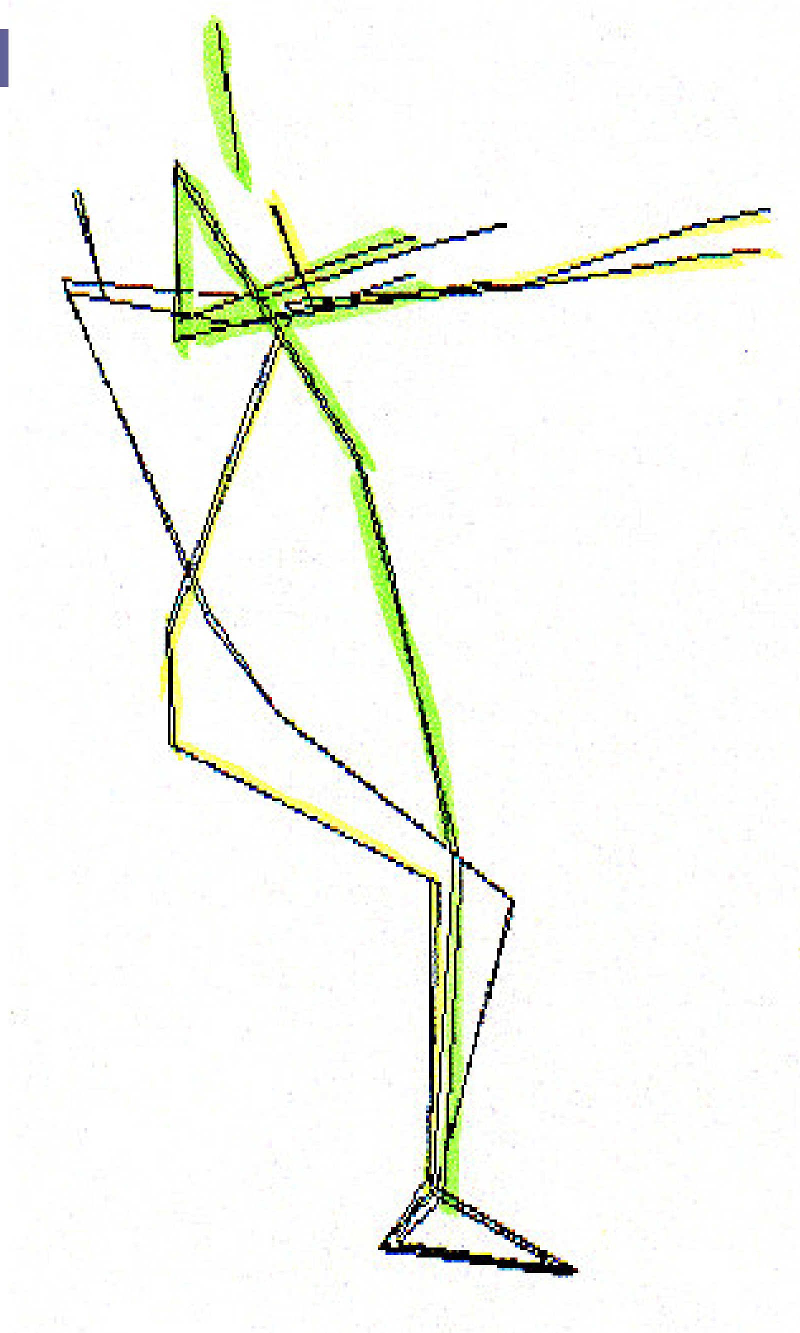
NO WIND PUMPING

Photo 1. Set up for the windsurfing pumping ergometer.

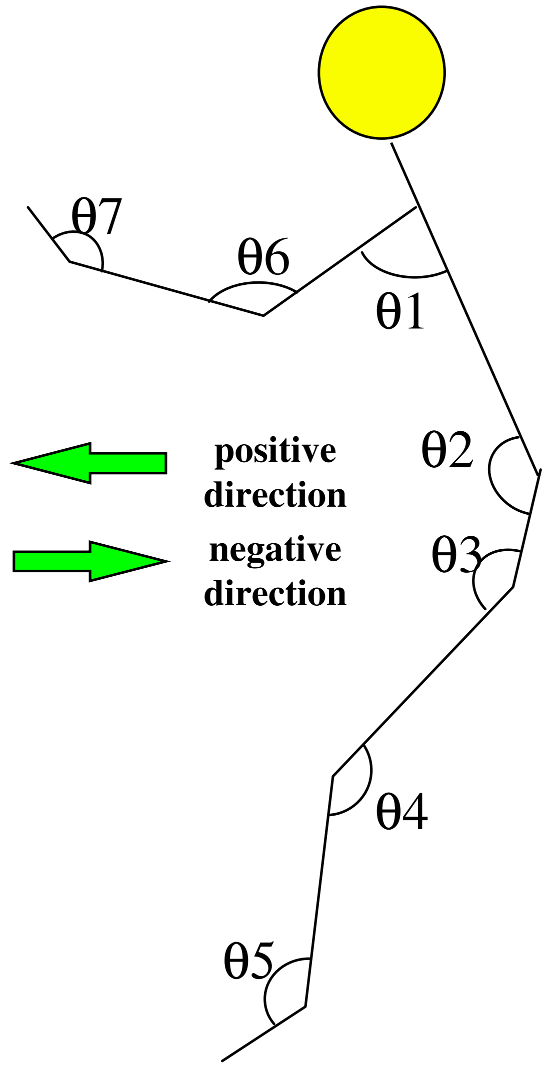
Kinematic Analysis



Peak 3D Motion Measurement system (USA)



Joint Angle Diagram



JOINTS

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

Test

3 minutes continuous ("up wind" style)

Data analysis

3 consecutive pumping cycles were

selected at the 5th and 170th seconds

of the 3-minutes pumping.

First 3 cycles -

unfatigued state condition

Last 3 cycles -

fatigued state condition

<u>Hand Movement</u>

(average speed in pulling phase) (cm/second)

Non-fatigue	Fatigue	p
114.8 ± 60.7	97.5 ± 57.2	0.006(sig)

(less energy to oppose the tension of the pumping Ergometer)

Center of mass - estimated using the video joint kinematics

	Non-fatigue	Fatigue	P
Average speed - vertical direction (cm/second)	35.1 $\pm$ 12.7	26.4 $\pm$ 6.2	0.041(sig)

(less energy available in fatigue cycle)

- The decrease of the CG (center of gravity) vertical displacement might be a consequence of a **modified motor strategy** for the purpose to **maintain the power output** during pumping the ergometer. Such change of motor strategy might be due to **muscle fatigue**.

Only pulling speed of shoulder and wrist joints were dropped significantly,

Not their respective rage of motion,

Windsurfers might be trying to maintain the range of motion by sacrificing the speed of the same joint.

Buchanan et al (1996)

- Windsurfers performed pumping on ergometer - EMG assessment

Muscles	*Actively*
Arm - flexor carpi ulnaris, extensor carpi radialis, biceps brachii.	*Greatest*
Deltoid, trapezius	*Considerable*

Joint	Movement Pattern Change
Elbow Shoulder (extension/flexion) Knee	No change
Ankle	- Delayed by about 5%
Hip	- Extend and finish earlier by about 5%
Shoulder (abduction/adduction)	- Delayed in reaching maximum abduction angle till the end of pulling cycle.
Wrist Waist	- No general trend

- Muscle fatigue might affect the muscle activation and consequently affect the original motor strategy during windsurfing pumping.

- **Kautz et al. (2000)** commented that fatigue influence muscle coordination during sporting movement as avoiding excess fatigue is an important consideration of the nervous system.

There is a need of specific muscle training for the windsurfers to meet the demands of competitive windsurfing with continuous pumping

Rodacki et al. (2001)

- sequential motion of the segments -- muscular force
- which under fatigue -- change
- distinctive patterns of segment motions and/or muscle activation may emerge.
- **compensatory mechanisms** used to counterbalance the loss in the force due to fatigue.

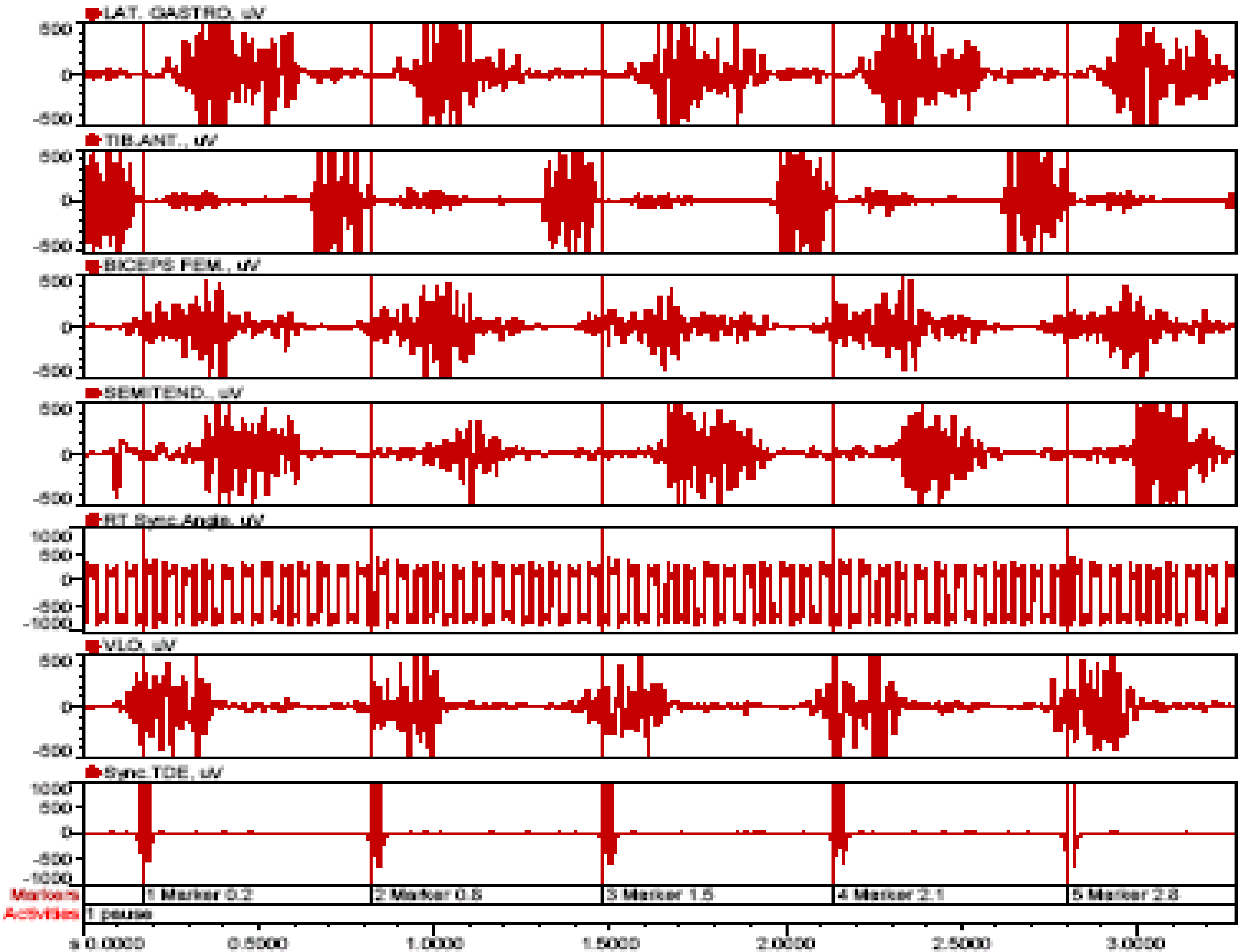
Bonato (2002)

Muscle fatigue may lead to compensatory muscular and biomechanical strategies during repetitive lifting.

- If the change of joints’ movement patterns was considering as a **compensatory** mechanism, it would be possible to assume that the original working muscles would be working at a lower intensity thus allowing time for the muscle to recover.

With **continuous monitoring** the fatigue pattern of working muscles, the strategies of recruiting muscles can be systematically documented.

EMG


LAT. GASTRO, uV
TIB.ANT., uV
BICEPS FEM., uV
SEMITEND., uV
RT Sync Angle, uV
VLO, uV
Sync.TDE, uV
Markers
Activities
1 Marker 0.2
2 Marker 0.8
3 Marker 1.5
4 Marker 2.1
5 Marker 2.8
1 pause
s 0.0000
0.5000
1.0000
1.5000
2.0000
2.5000
3.0000

EMG Power Frequency Spectrum shifts during repeated isokinetic knee and arm movements.

So R, Chan KM, Siu TO

Research Quarterly for Exercise and Sport 2002, 73(1), 98-106.

Isokinetic testing device : Cybex 6000

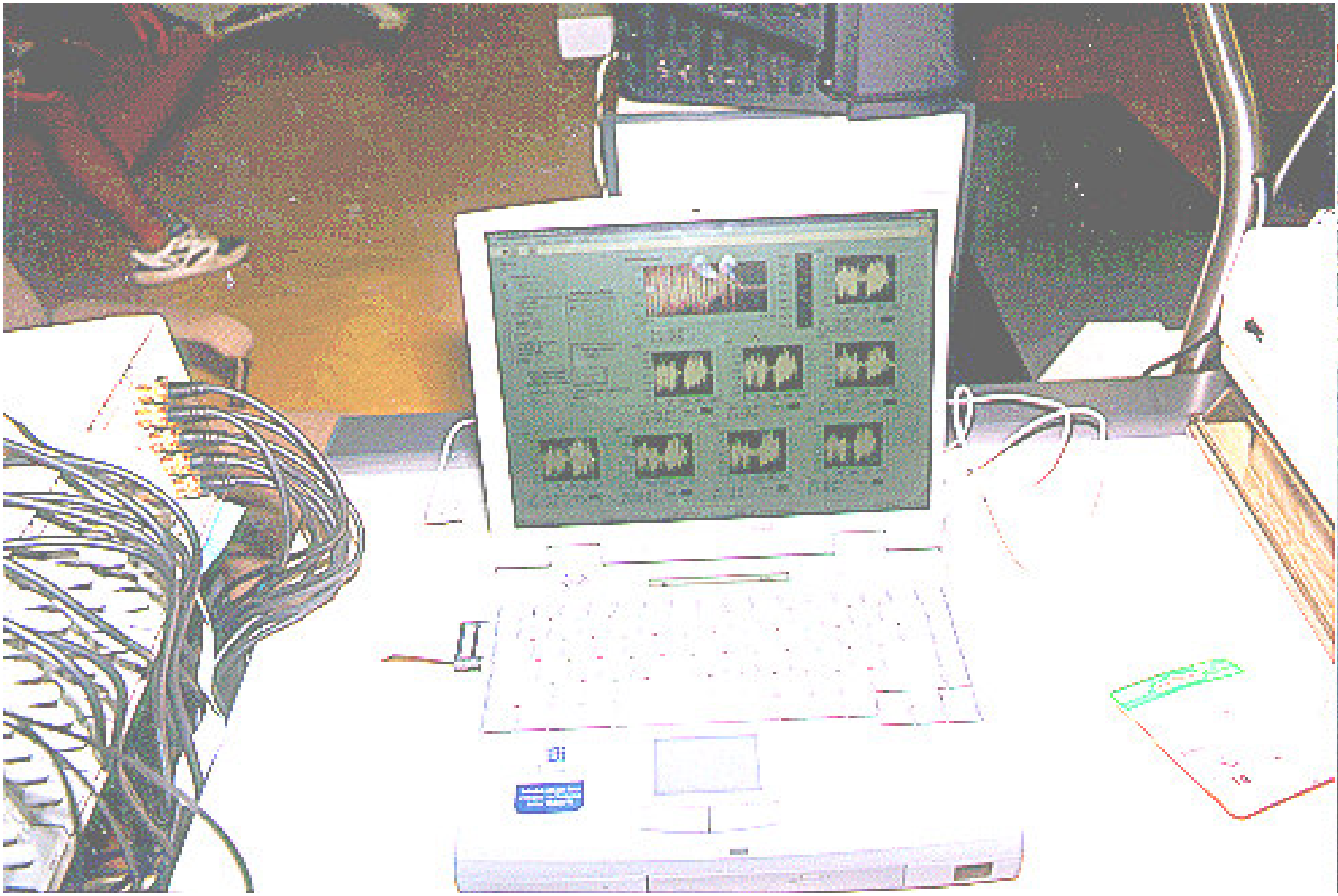
Movement :

Knee extension	-	**Rectus Femoris**
		Vastus Lateralis
Elbow flexion	-	**Biceps Brachii**
		Brachioradialis

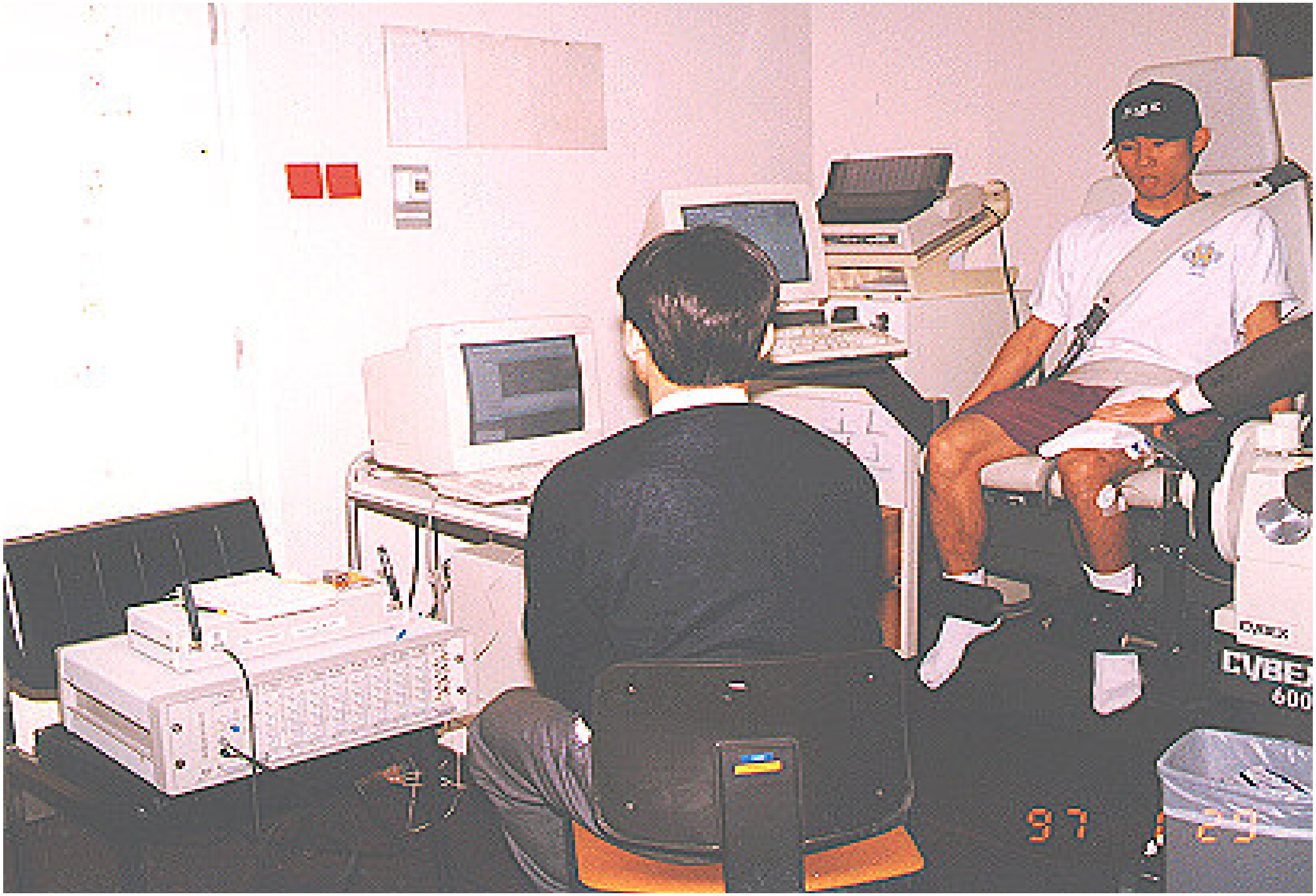
Testing speed : 180 deg / sec

Repetition : **Knee extension - 50**
Elbow flexion - 40

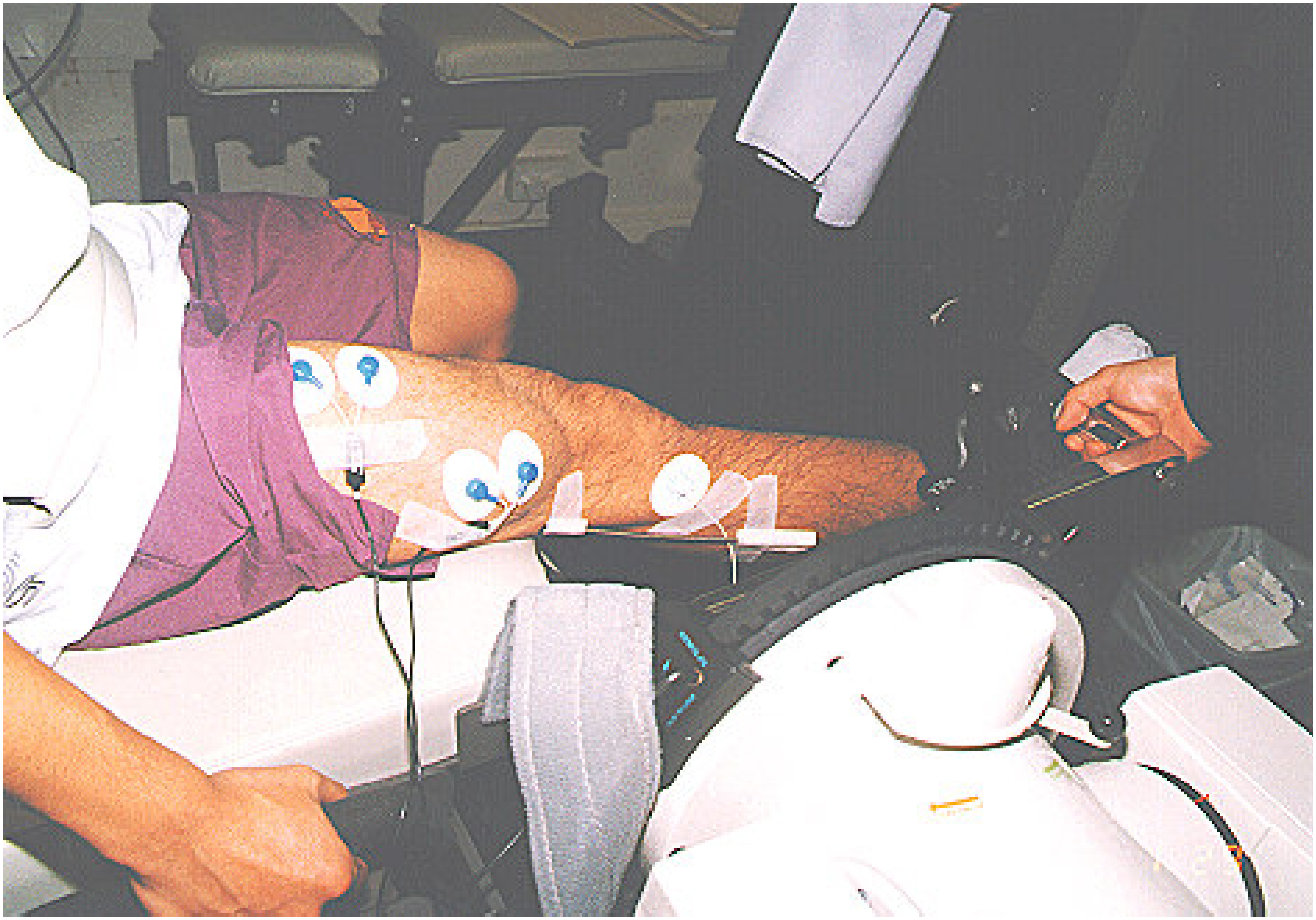
The Notebook computer for EMG data monitoring and storage.

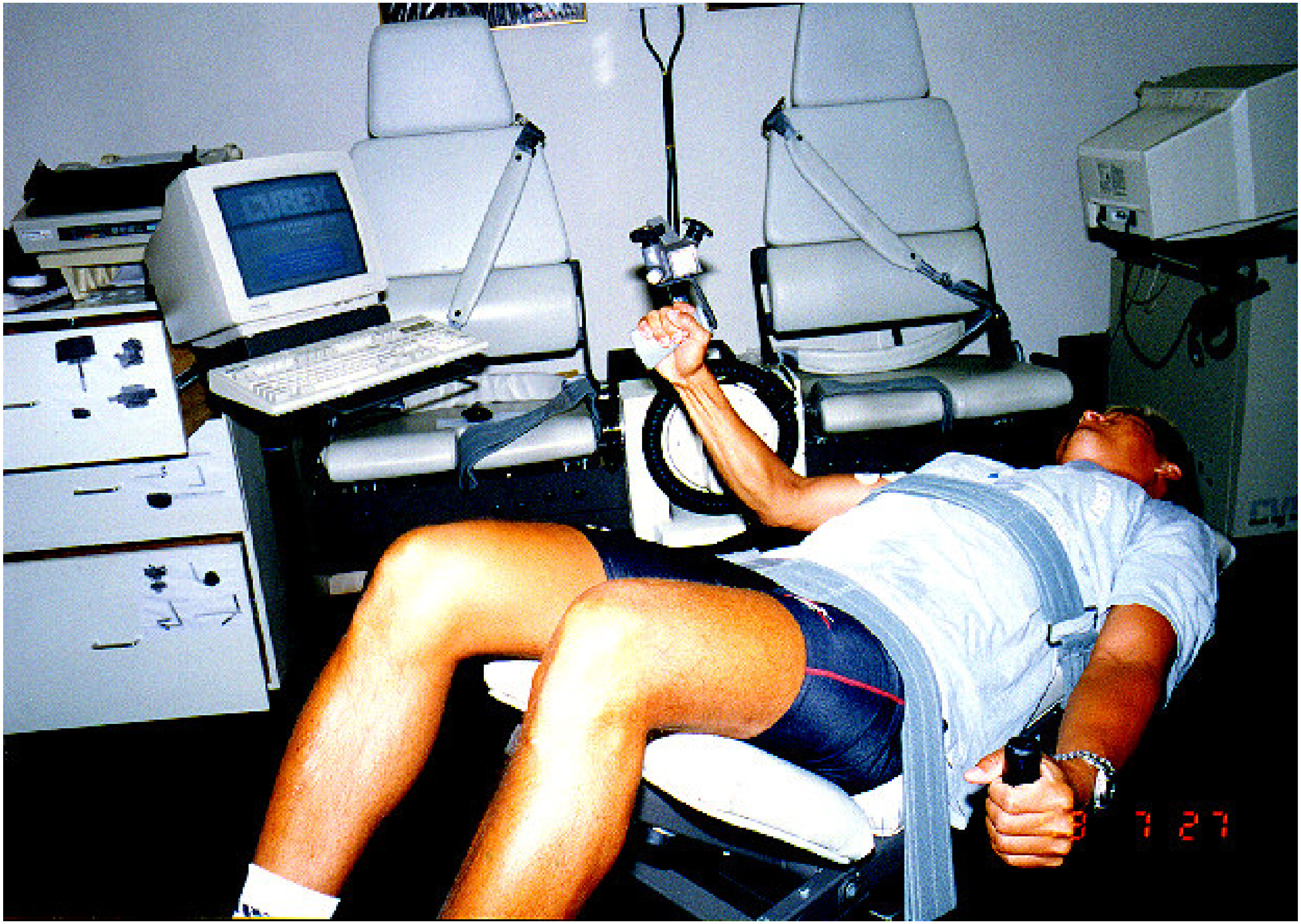


Set up for knee extension test with surface EMG assessment.



Electrodes attachment for knee extension test.





Each dynamic segment, a half second of EMG data was recorded. The start of EMG recording was triggered on during the start of the joint movement which was registered by the goniometer.

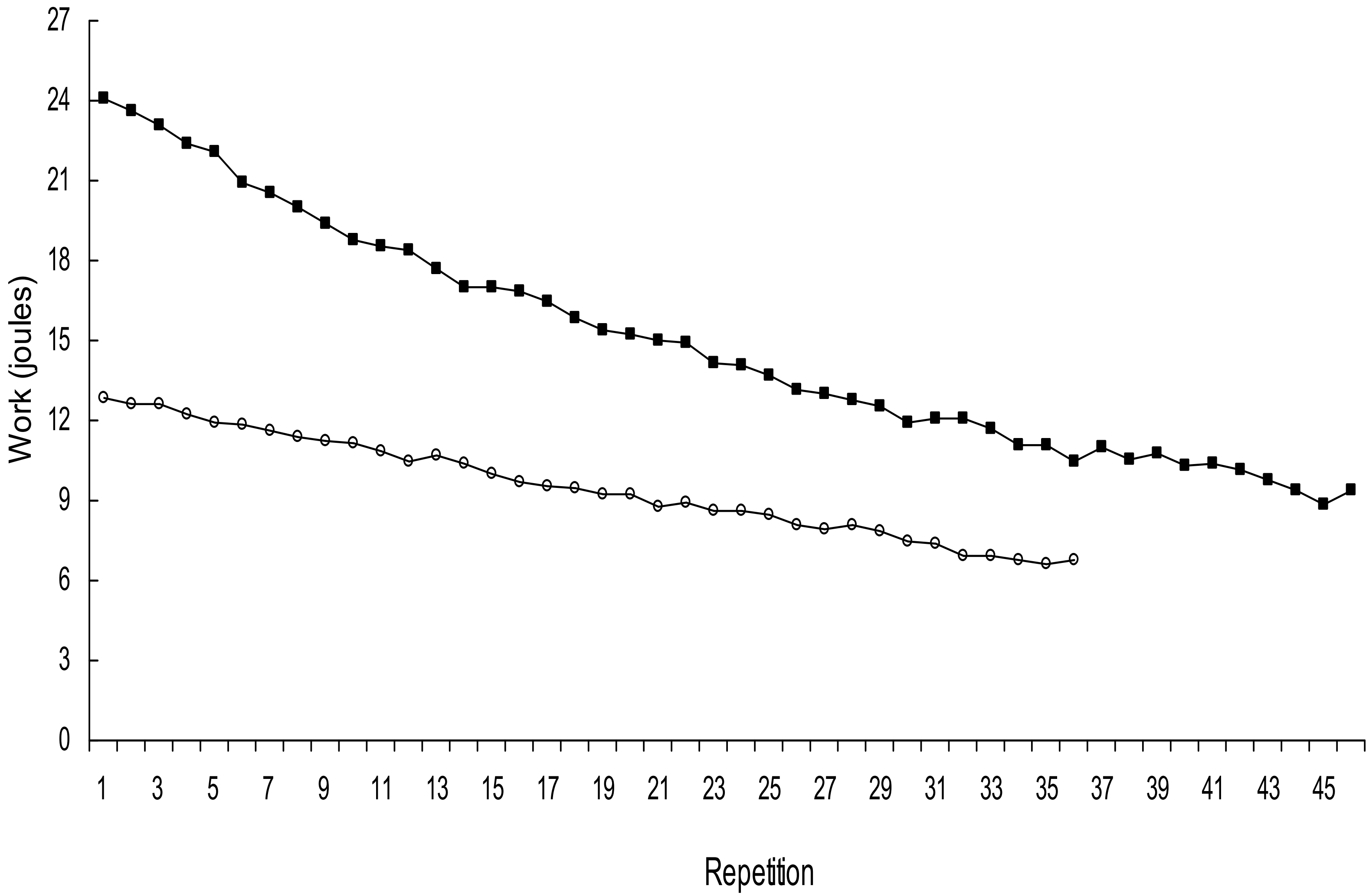
Fast Fourier transform was used to calculate the mean and median power frequencies of each segment.

RESULTS

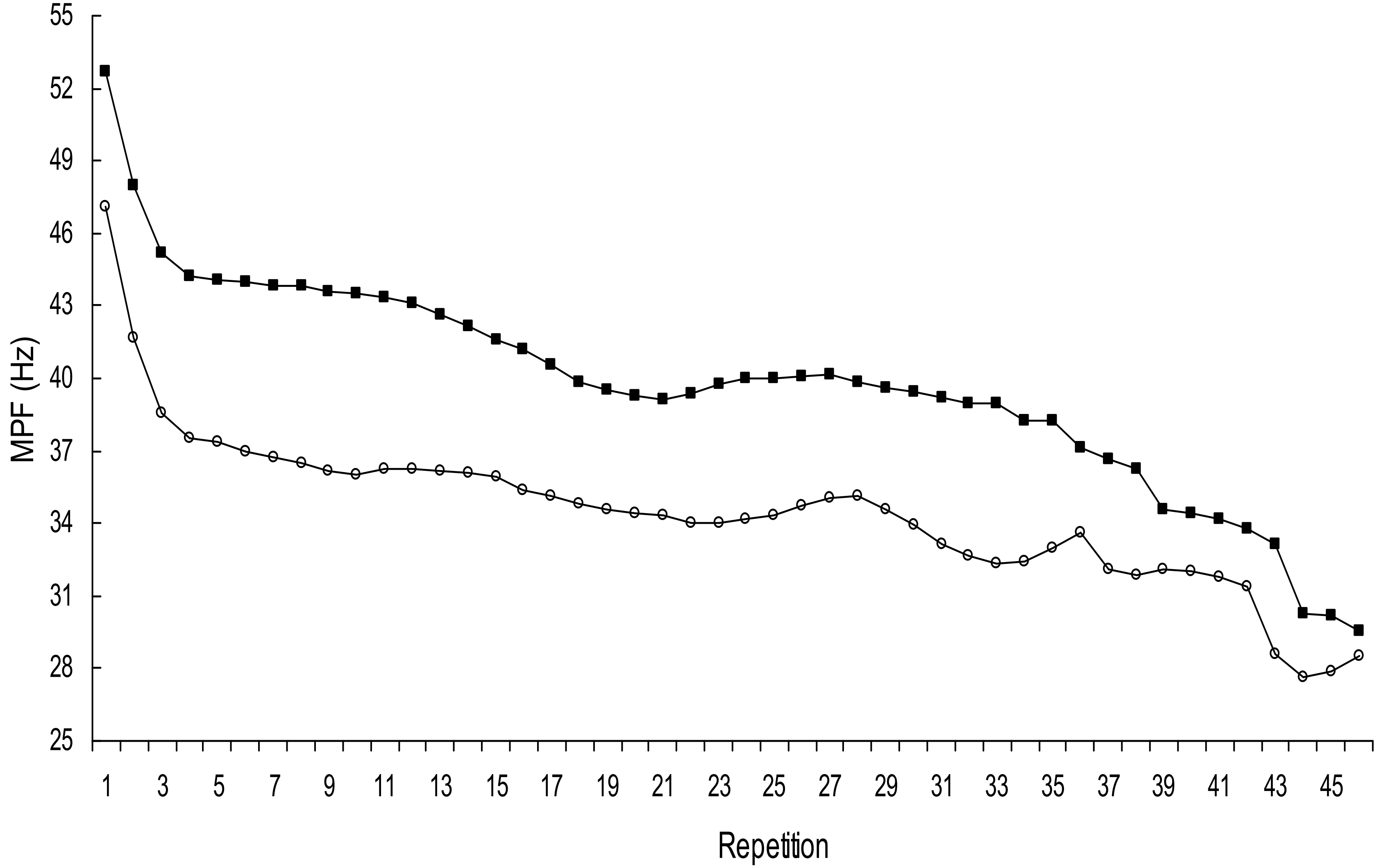
All the required analysis were started at the third repetition.

	Work output		
	Start	End	%drop
Knee extension	24.3	9.3	61.7
Elbow flexion	13.2	6.1	53.8

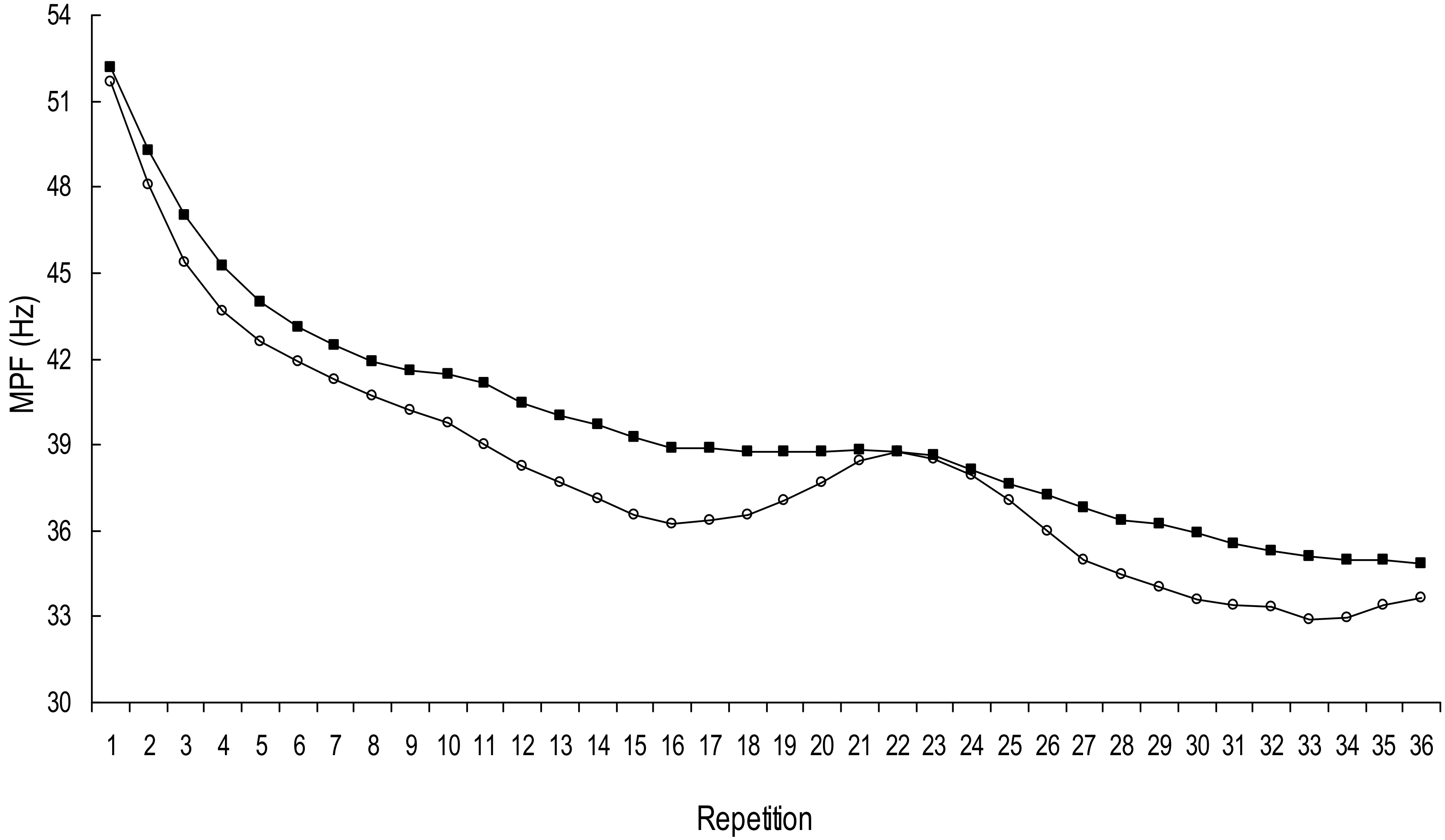
Work output during elbow flexion and knee extension exercises.



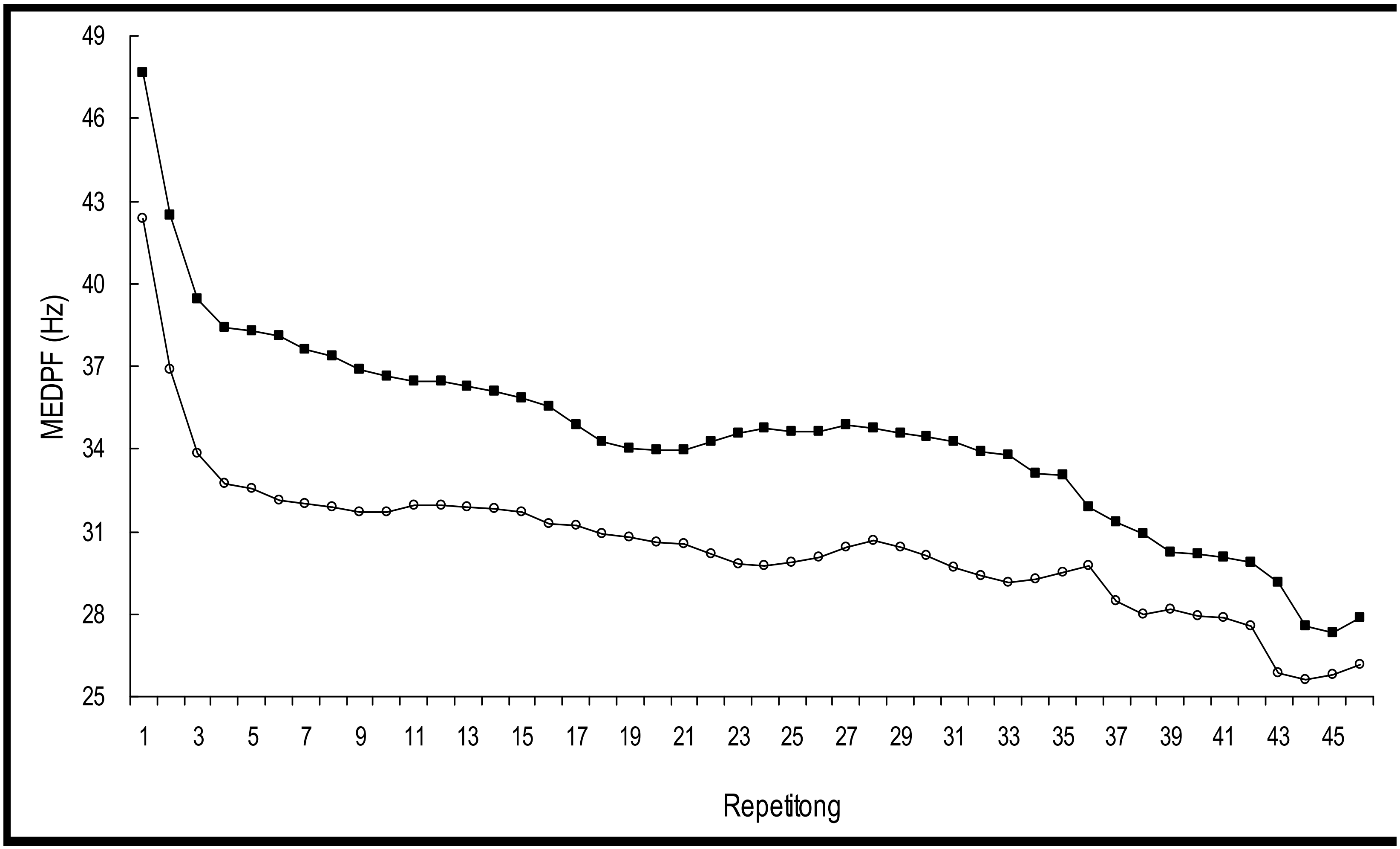
Mean power frequency (MPF) response measured on Vastus Lateralis and Rectus Femoris during knee extension exercise.



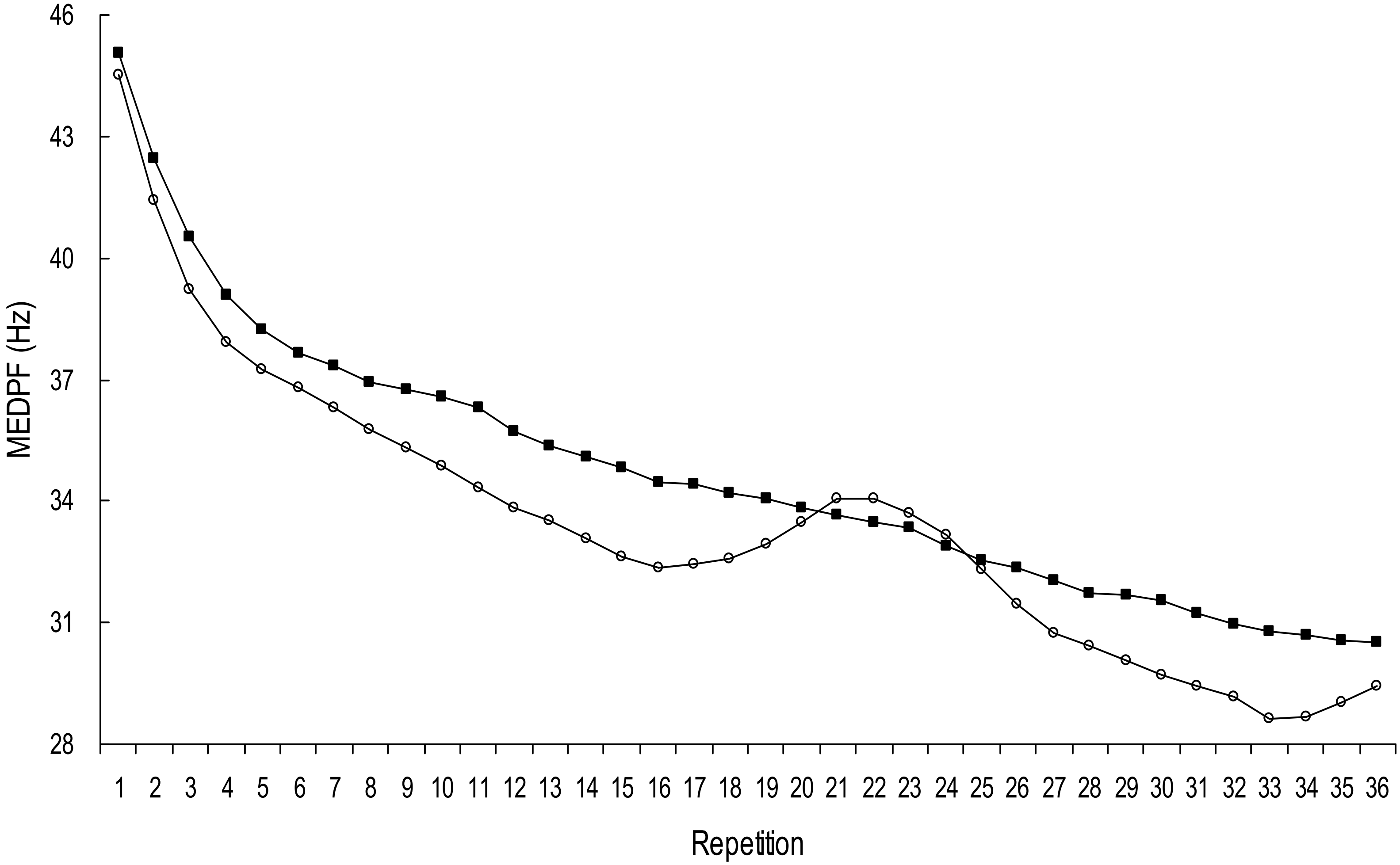
Mean power frequency (MPF) response measured on Brachioradialis and Biceps Brachii during elbow flexion exercise.



Median power frequency (MEDPF) response measured on Vastus Lateralis and Rectus Femoris during knee extension exercise.



Median power frequency (MEDPF) response measured on Brachioradialis and Biceps Brachii during elbow flexion exercise.



The change of the mean and median power frequencies of the assessed muscle groups. (Mean + SD)

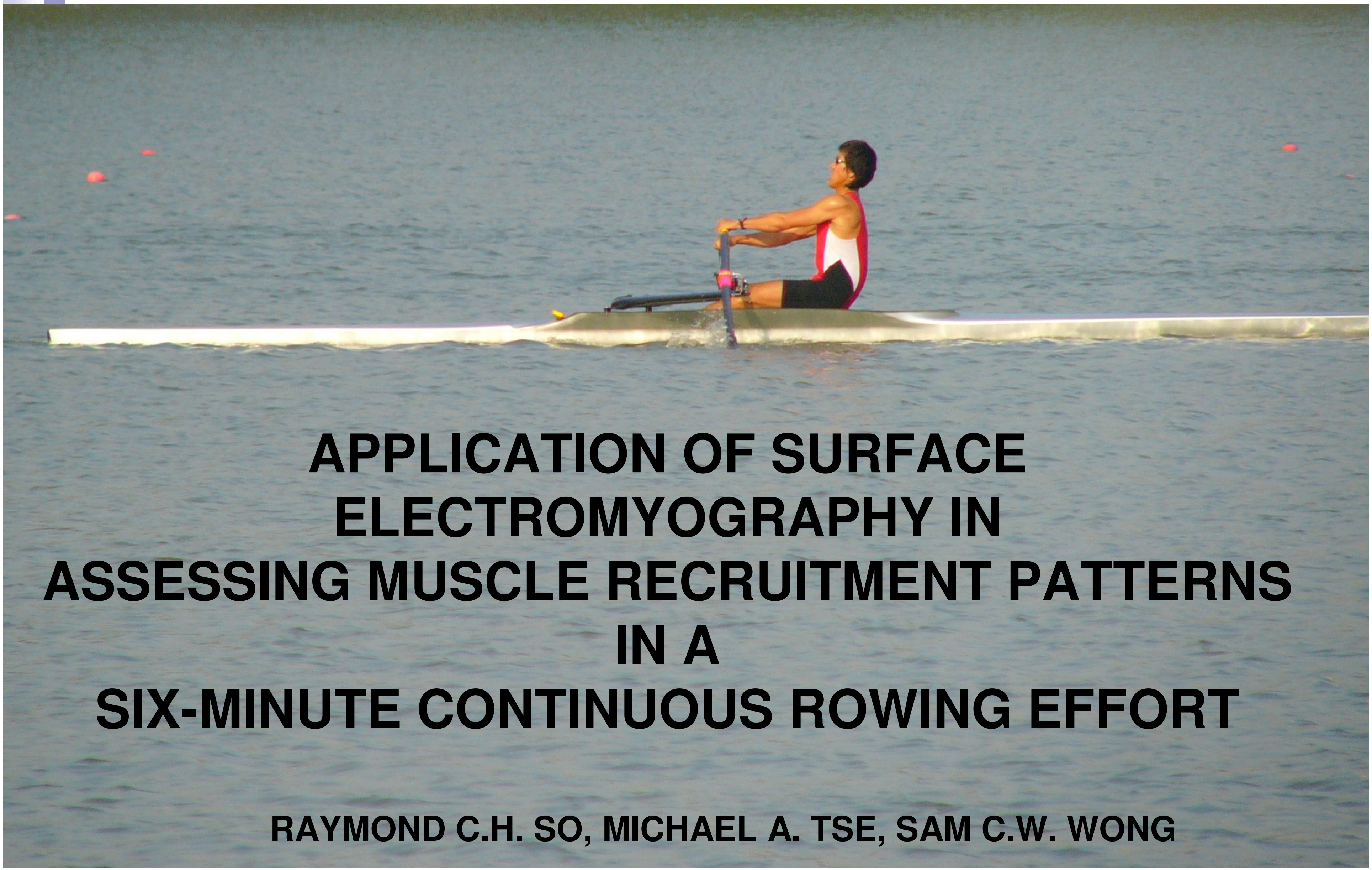
Muscles	Vastus Lateralis	Rectus Femoris	Biceps Brachii	Brachioradialis
Maximal MPF (Hz)	48.9+12.0	54.6+11.7	52.3+12.6	52.67+9.9
Minimal MPF (Hz)	30.1+5.3	34.2+5.9	31.9+3.5	32.86+2.9
Maximal MEDPF (Hz)	42.3+13.0	47.7+12.1	44.5+12.1	45.1+8.4
Minimal MEDPF (Hz)	25.6+2.6	27.3+2.8	29.0+3.2	30.6+2.6
Relative drop in MPF (%)	36.1+11.9	36.3+8.2	36.8+12.6	36.1+9.8
Relative drop in MEDPF (%)	38.5+13.4	40.5+11.1	36.9+12.6	36.6+9.5

The average drop of MPF and MEDPF in all the four muscle groups was about the same

37.2%

The correlation coefficients of the drop of work output and EMG power frequency for the four muscles

				MPF	**MEDPF**
R	**=**	**Vasts Lateralis**	**=**	**0.5611**	**0.5099**
		Rectus Femoris	**=**	**0.6300**	**0.5581**
		Biceps Brachii	**=**	**0.7384**	**0.7483**
		Brachioradialis	**=**	**0.7061**	**0.7366**



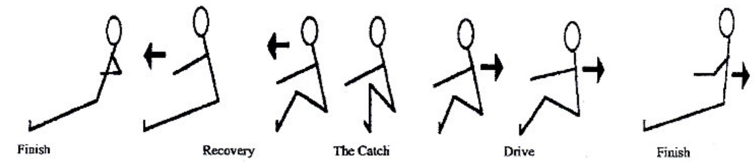
APPLICATION OF SURFACE ELECTROMYOGRAPHY IN ASSESSING MUSCLE RECRUITMENT PATTERNS IN A SIX-MINUTE CONTINUOUS ROWING EFFORT

RAYMOND C.H. SO, MICHAEL A. TSE, SAM C.W. WONG

Journal of Strength and Conditioning Research, 2007, 21(3), 724–730

Rowing stroke

FIGURE 1—Phases of the rowing stroke (*arrow* depicts motion of the trunk).



Holt et al. (2003)

- At the catch, the rower makes the initial movement of the stroke by extending the back slightly, while allowing further flexion of the legs.
- After a few percent of the stroke the legs continue to accelerate the handle, while the back resists the force isometrically.
- After about 10% of stroke (at approximately ⅓ of the drive phase), the legs continue to extend as the back accelerates toward extension to maintain the force generation.
- The stroke ends with the hand pull.

- They reported that prolonged rowing would deteriorate this technique by increasing the maximum angle of flexion of the spine and the range of spinal movement.
- How muscle fatigue affects muscle recruitment patterns during continuous rowing

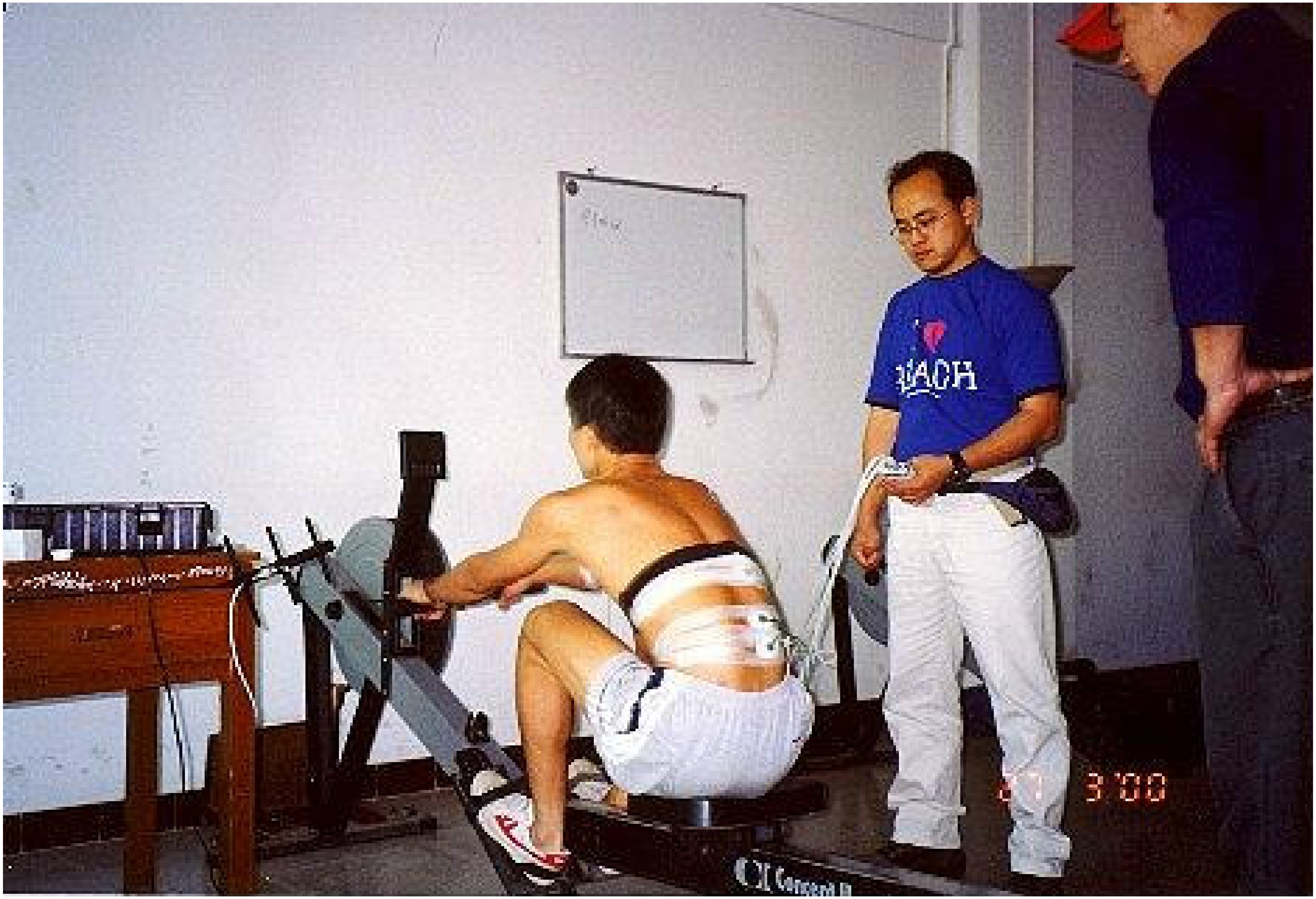
The average pace and blood lactate result after 6 minutes of rowing

	Average pace (min:sec/500m)	Blood lactate (mM)
HK Olympic	1:42.1±0.5	14.1±0.7
Guangzhou	1:46.1±0.8	13.2±0.8
HK Youth	1:54.2±5.5	13.6±2.4

The mean pace result and *SD* of the fast and slow subgroups of the Provincial and Youth groups after 6 minutes of rowing.

Subgroups	*N*	Pace (min:sec per 500 m)
Provincial, fast	2	1:45.3±0.2
Provincial, slow	3	1:46.7±0.8
Youth, fast	4	1:50.0±2.9
Youth, slow	5	1:57.5±5.2


1018



Surface EMG signal :

Brachioradialis
Biceps brachii
Mid-Deltoid
Rectus abdominis
Erector spinae
Quadriceps
Hamstring

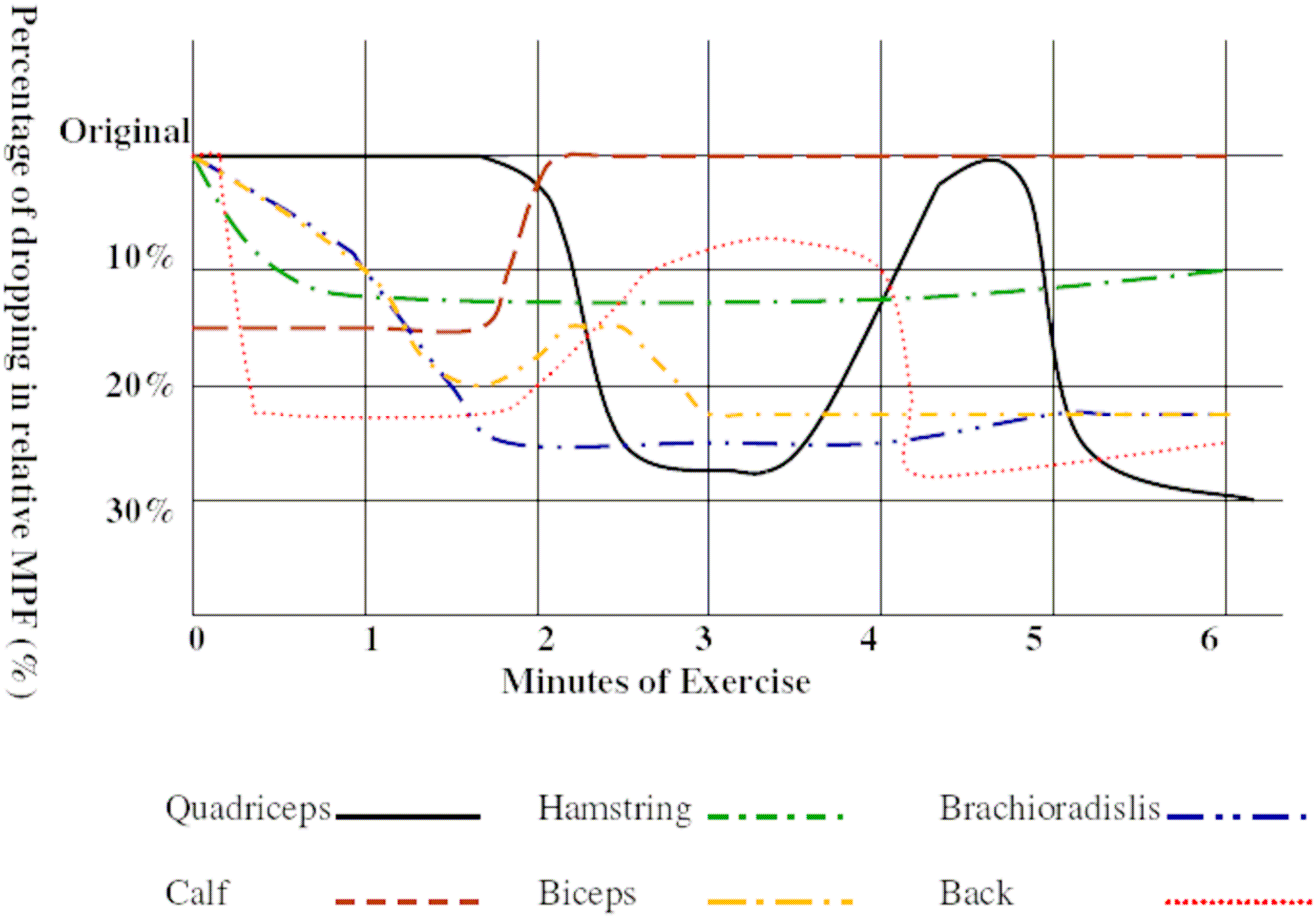


Fig. 1. The relative MPF changing patterns of the assessed muscle-Olympic Team

- **Kuorinka (1988)** stated that after dynamic fatigue workout, the restitution of surface EMG power frequency (an indicator of muscle fatigue) followed a logarithmic course; the original level of the MPF was recovered mostly during the first 1 to 3 minutes of recovery

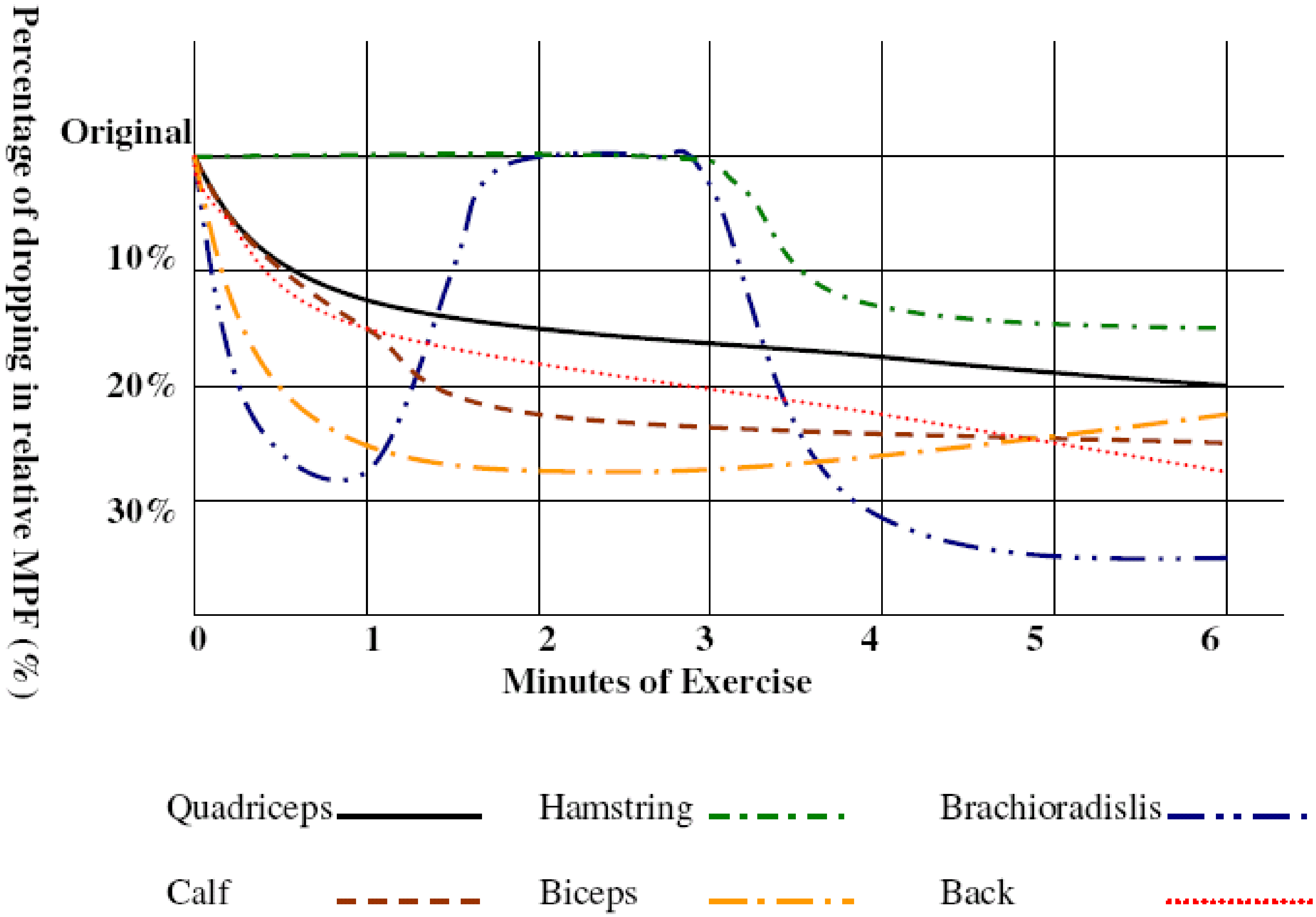


Fig. 2. The relative MPF changing patterns of the assessed muscle-Provincial Team-fast

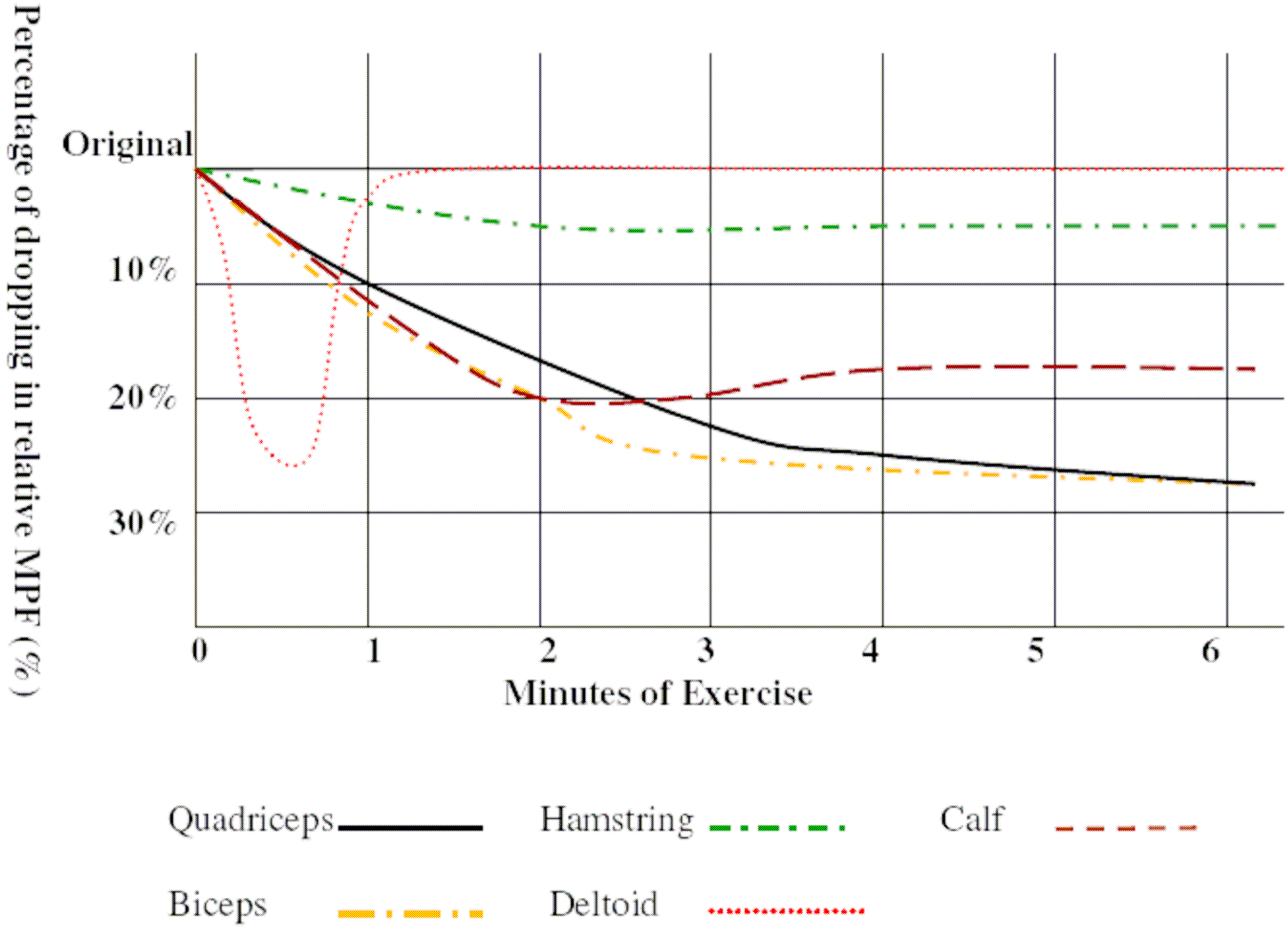


Fig. 4. The relative MPF changing patterns of the assessed muscle-Youth Team-fast

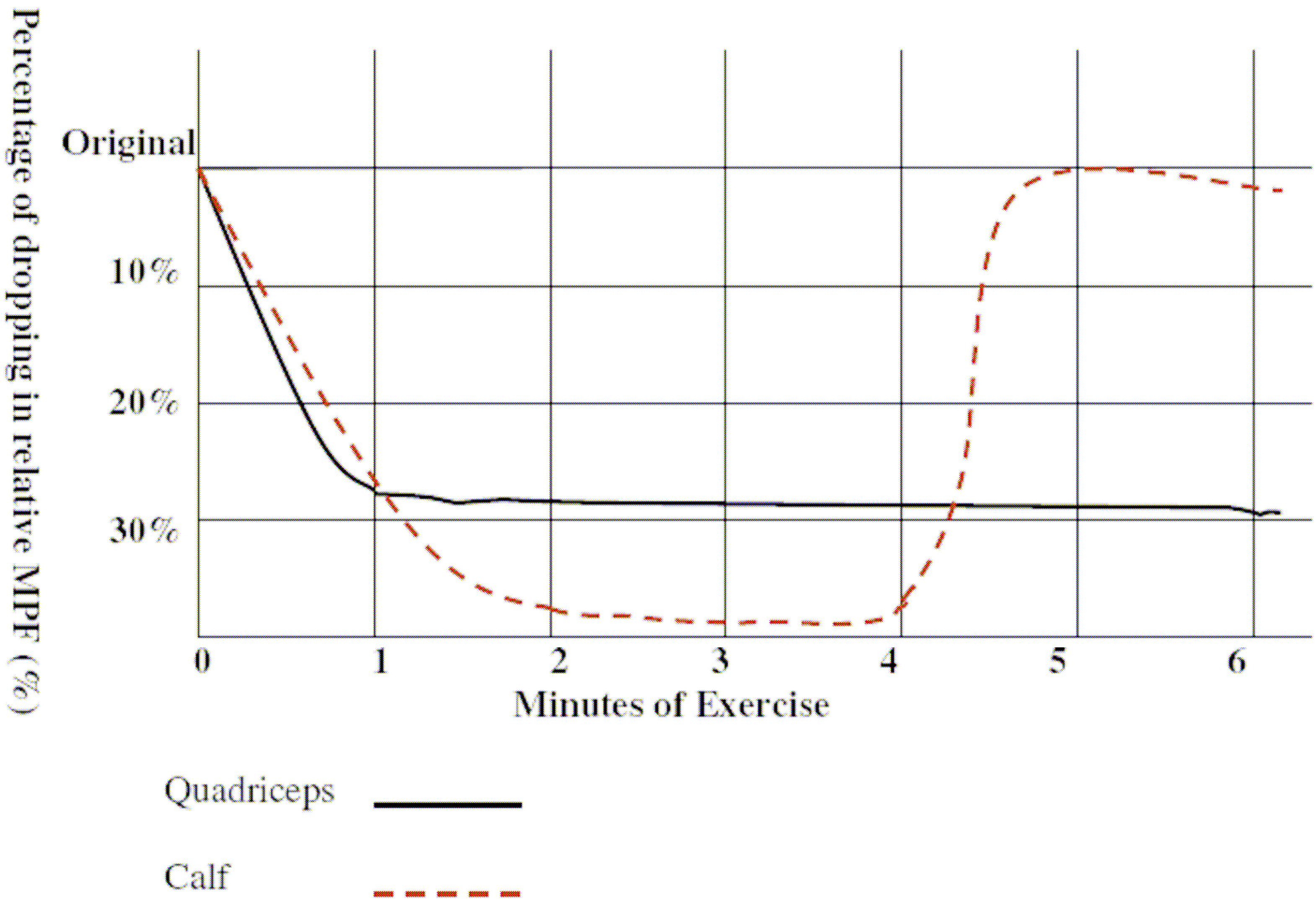


Fig. 5. The relative MPF changing patterns of the assessed muscle-Youth Team-slow

- Clear muscle alternation strategies were noted in both the Olympic and Fast-Provincial rowers.
- The weaker rowers, there was no shifting of work between different working muscles to allow time for fatiguing muscles to recover while others took up some of the work
- **biodynamic compensation**

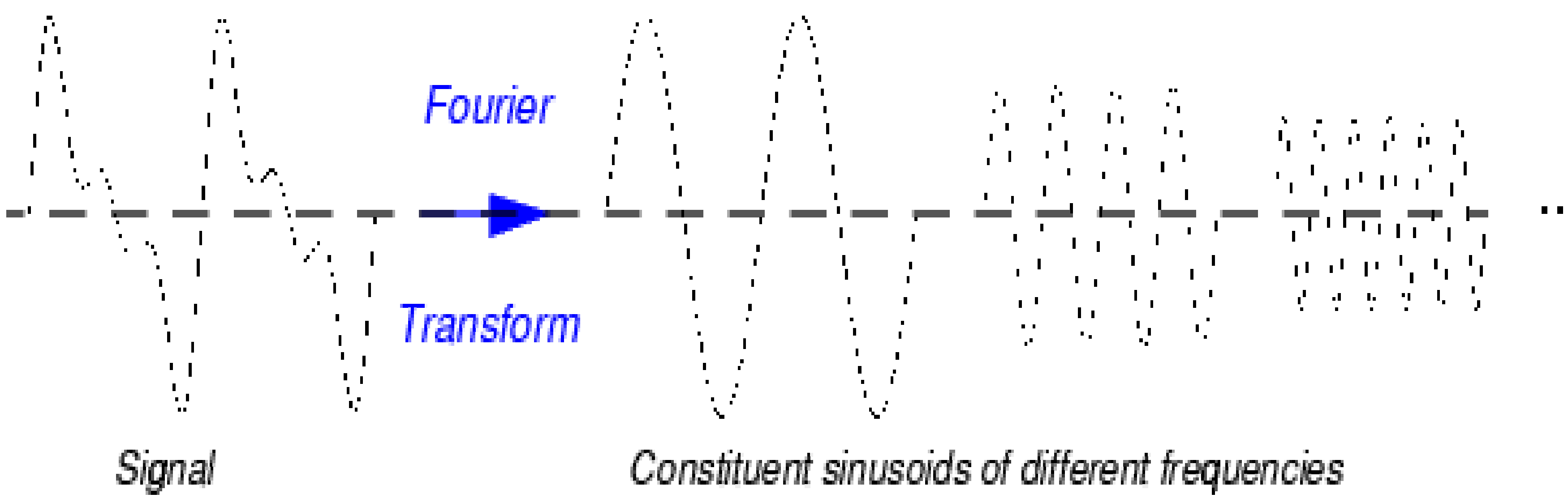
Maximum continuous rowing

- start with all muscles,
- emphasizing the back muscle
- and then switching the emphasis of utilization between the quadriceps and back muscle for 1-minute intervals throughout the exercise bout.

- That optimal recruitment patterns tend to involve the utilization of large muscle groups first, followed by subsequent sharing of work between these muscle groups as fatigue sets in.
- With less experienced rowers, all muscles are used from the start with early fatigue of small muscle groups such as muscles of the arms and calves.

- The ability to recruit the muscles alternately might not just contribute to the faster pace, but might also be an important factor for athletes to maintain a given force output during the whole course of exercise
- Rowers have to know how to alternate the recruitment of major muscles during high-intensity rowing exercise or competition.

To obtain EMG power frequency - Fourier analysis.
It has a serious drawback. In transforming to the frequency domain, time information is lost - *stationary* signal



However, most interesting signals contain numerous *nonstationary* or transitory characteristics:
drift, trends, abrupt changes, and beginnings and ends of events.

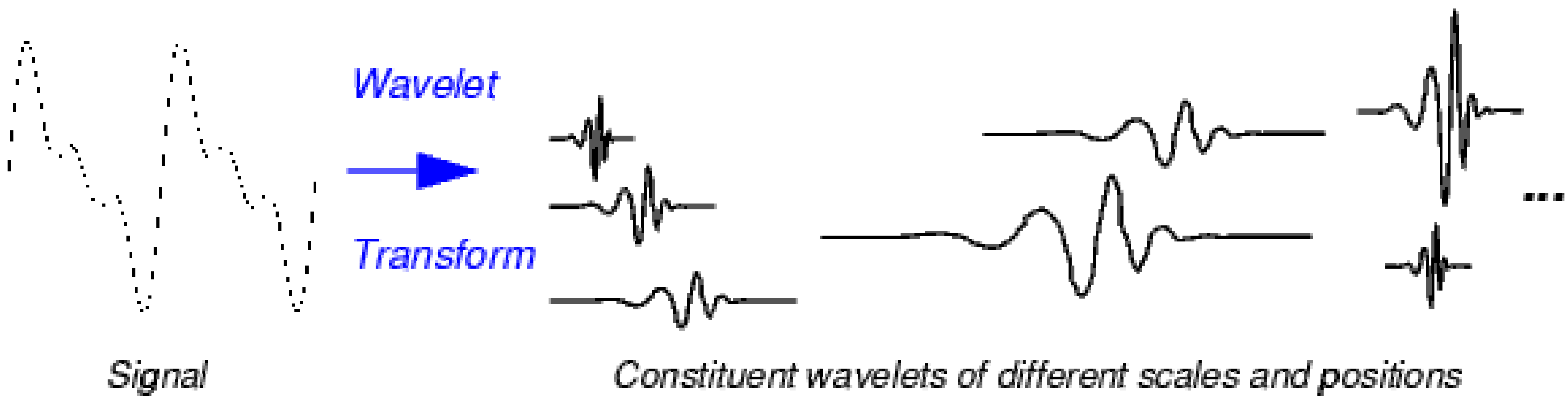
These characteristics are often the most important part of the signal, and Fourier analysis is not suited to detecting them.

Wavelet analysis

- Wavelet transform is a time-frequency analysis method that quantifies temporal changes of the frequency content of non-stationary signals without losing resolution in time or frequency.

- Wavelet analysis studies sEMG signals in a very short duration **(Karlsson et al. 2000),** so that the change in timing and frequency content can be evaluated simultaneously, which is important for analyzing dynamic activities.

Wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or *mother*) wavelet.



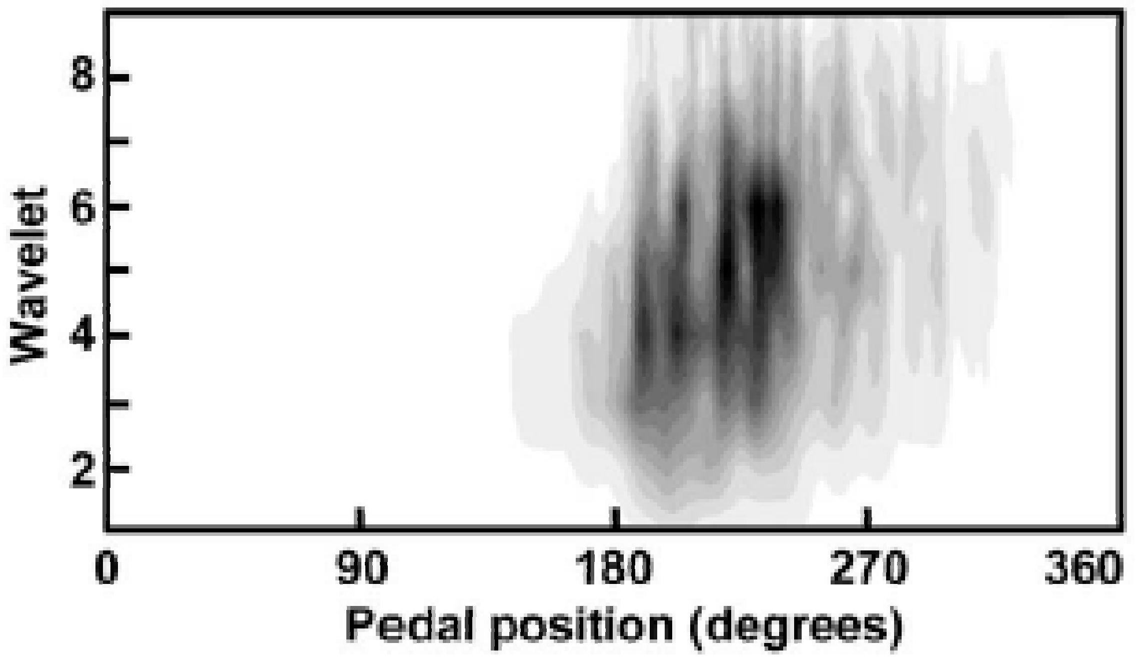


Fig. 2. Intensity-pattern of a single trial (trial 2) of the gas. med. muscle of subject 3.

Von Tscharner 2002

Wavelet analysis can reveal at which pedal position and at what wavelet (frequency) changes occurred because of fatigue

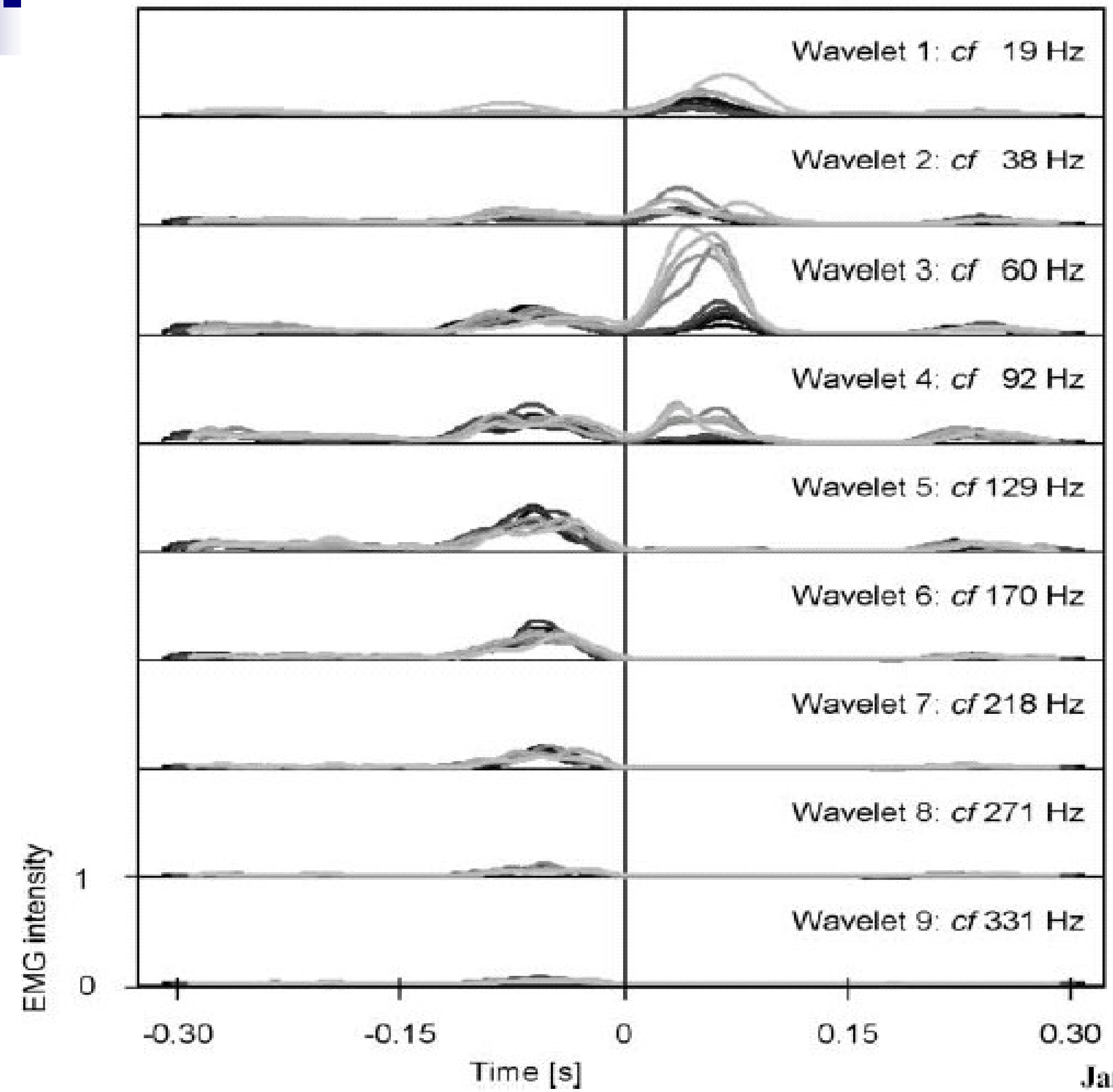


Fig. 2 EMG intensities for the biceps femoris during a 30-min run at 3.9 $m \cdot s^{-1}$. Time 0 denotes heel-strike. Each line is the mean intensity for a stride calculated from ten consecutive steps. The intensities at each wavelet domain are normalised to the maximum value that occurred at wavelet 3. The initial lap is denoted by the *light grey line* and the lines are graded to the last lap, which is denoted by the *black line*. Data are shown for the 1st and last 4 laps from a 15-lap run. The centre frequency (*cf*) is given for each wavelet domain

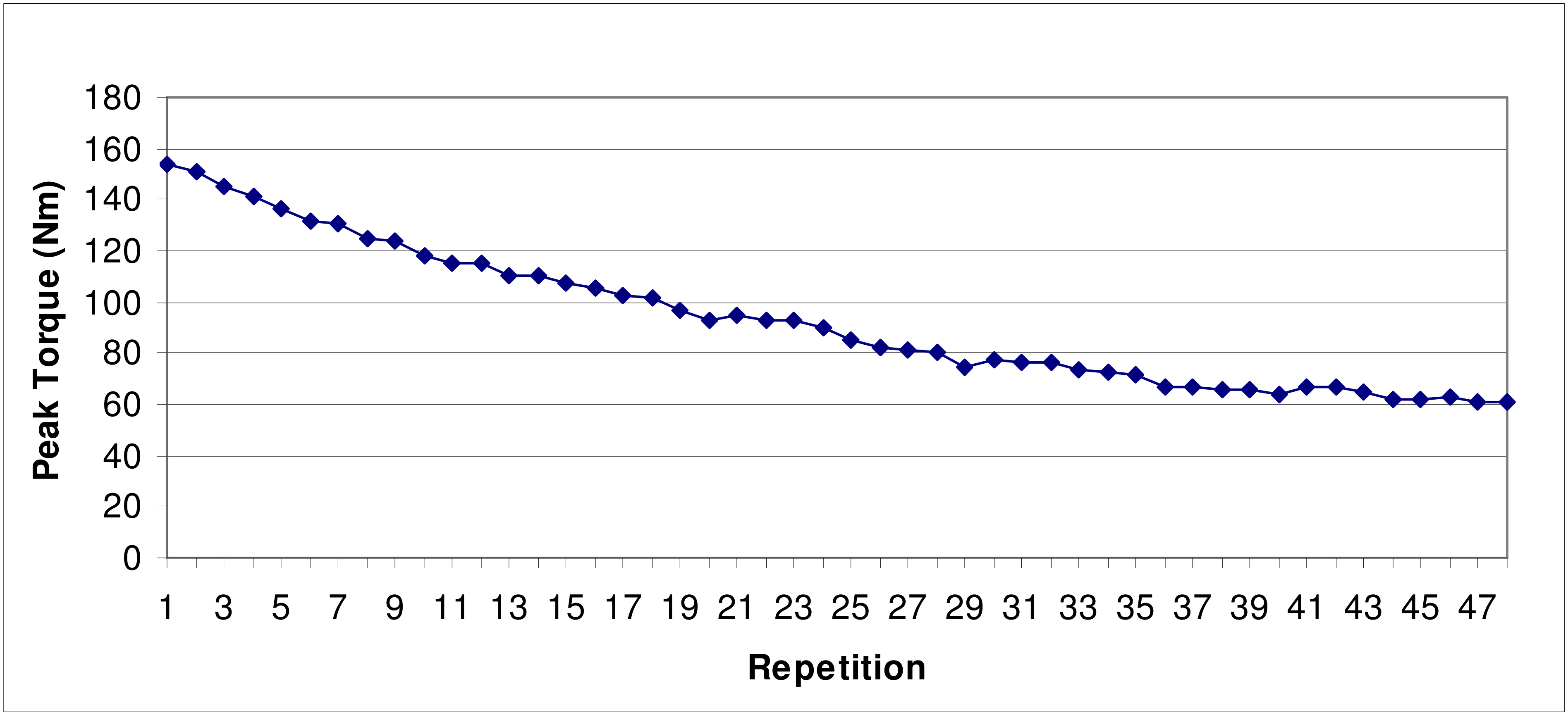
James M. Wakeling · Silvia A. Pascual
Benno M. Nigg · Vinzenz von Tscharner
Eur J Appl Physiol (2001) 86: 40–47

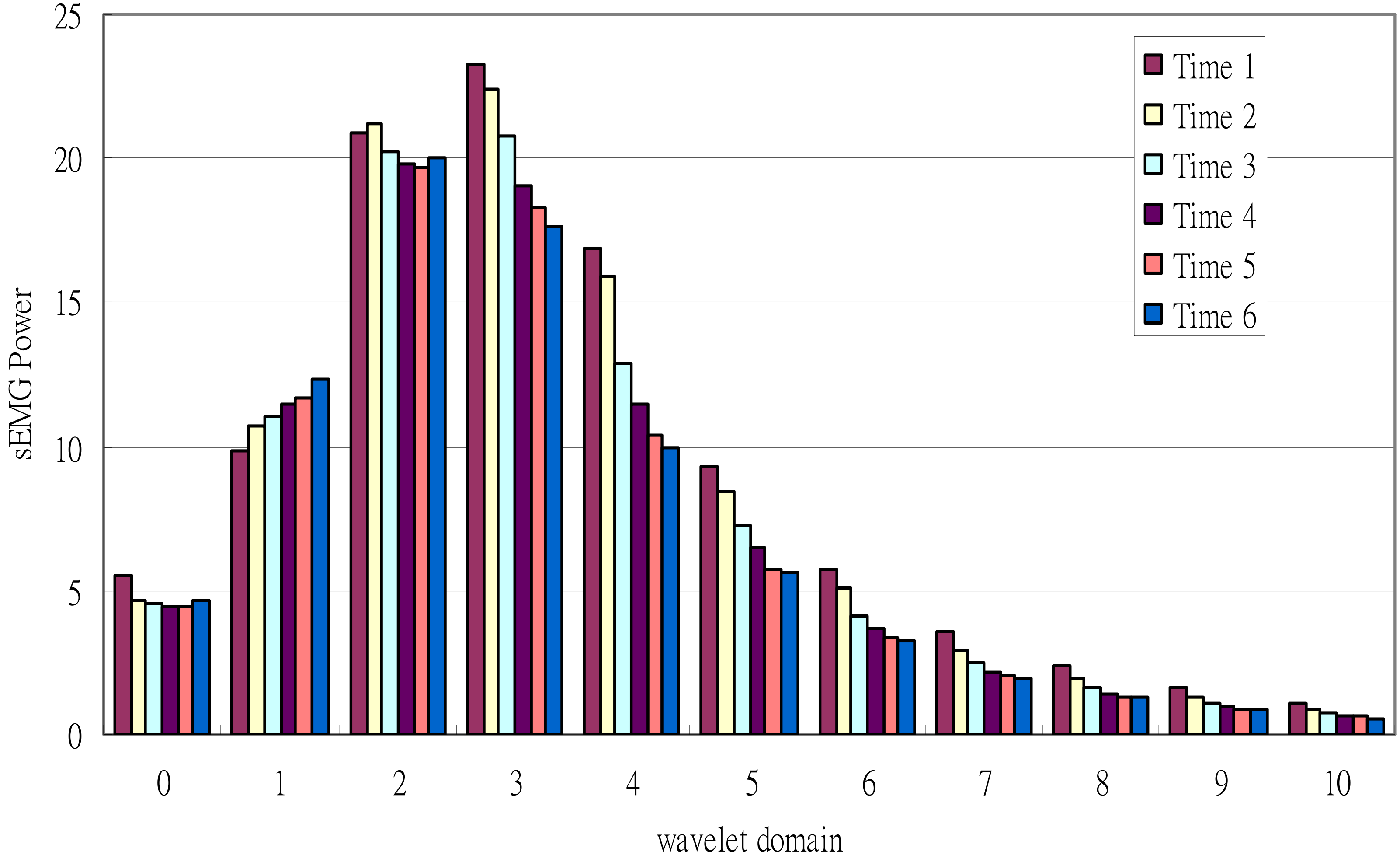
Electromyographic time-frequency (wavelet) analysis of quadriceps muscle during repeated knee extension movement

Raymond C.H. So,
Joseph K.-F. Ng,
Ringo W.K. Lam,
K.K. Lo,
Gabriel Y.F. Ng

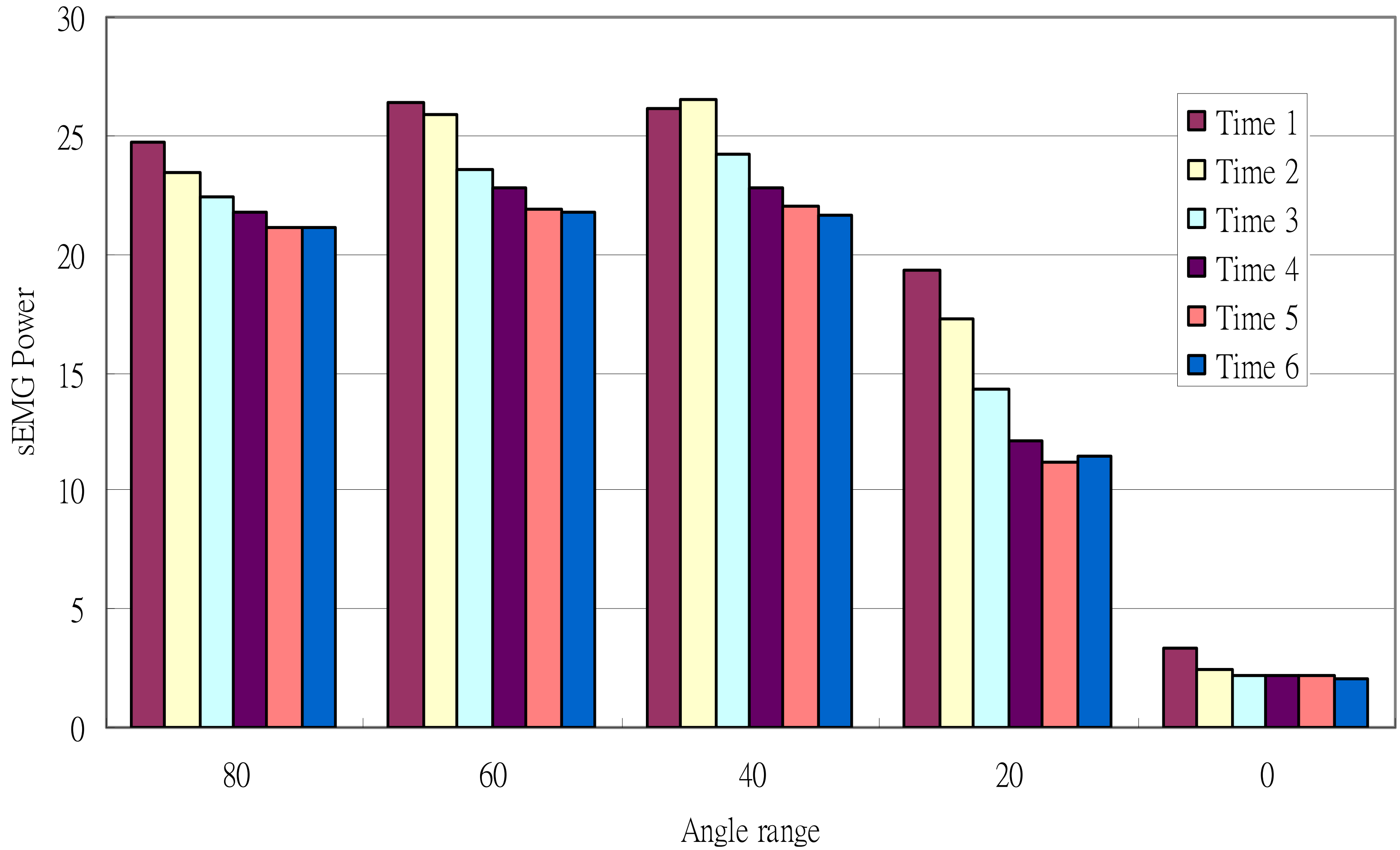
- N=11young males
- Maximal isokinetic knee extension and flexion exercise
- 50 repetitions at 180° sec-1 and at a range of 100°-0°.
- Surface EMG (sEMG) : vastus medialis (VM), vastus lateralis (VL) and rectus femoris (RF)

Peak torque output of each repetition of knee extension exercise during the maximal continuous exercise





25
20
15
10
5
0
sEMG Power
0
1
2
3
4
5
6
7
8
9
10
wavelet domain
Time 1
Time 2
Time 3
Time 4
Time 5
Time 6



30
25
20
15
10
5
0
sEMG Power
80
60
40
20
0
Angle range
Time 1
Time 2
Time 3
Time 4
Time 5
Time 6

- The most significant and consistent trend of decrease in sEMG power under maximal knee extension exercise for vastus medialis, vastus lateralis and rectus femoris was identified at the angle range of 40°-20° of wavelet domain 4.

Muscle activity shift during high intensity cycling: a time series analysis

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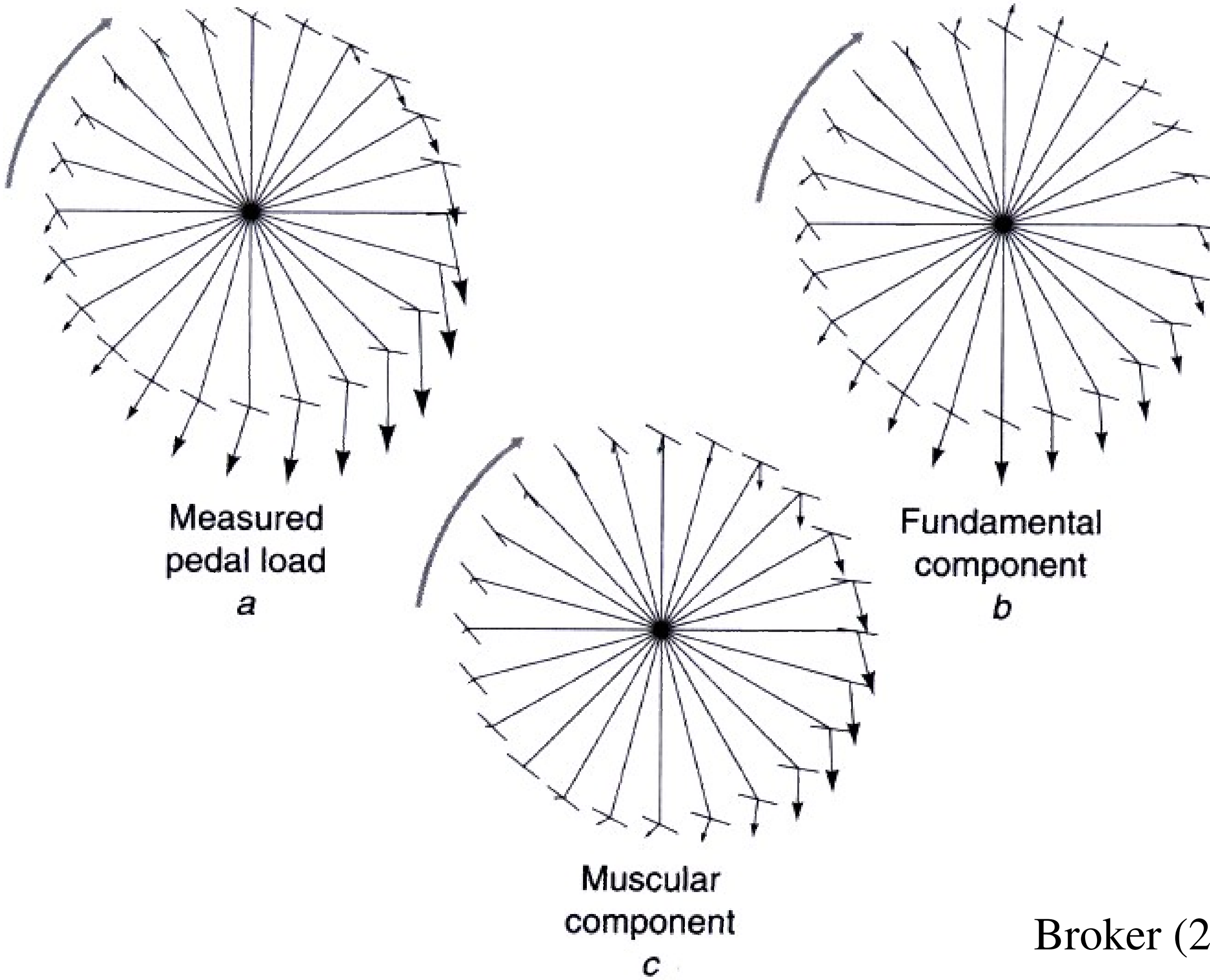
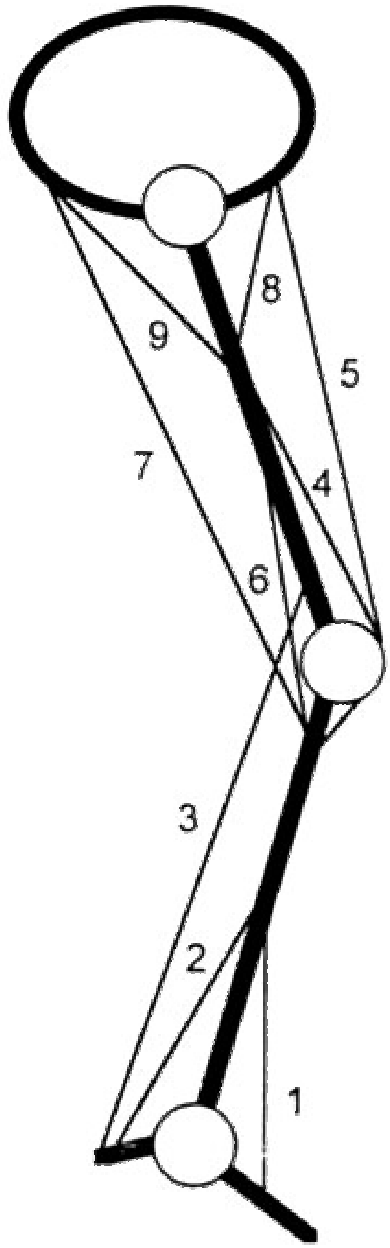
Muscle Recruitment



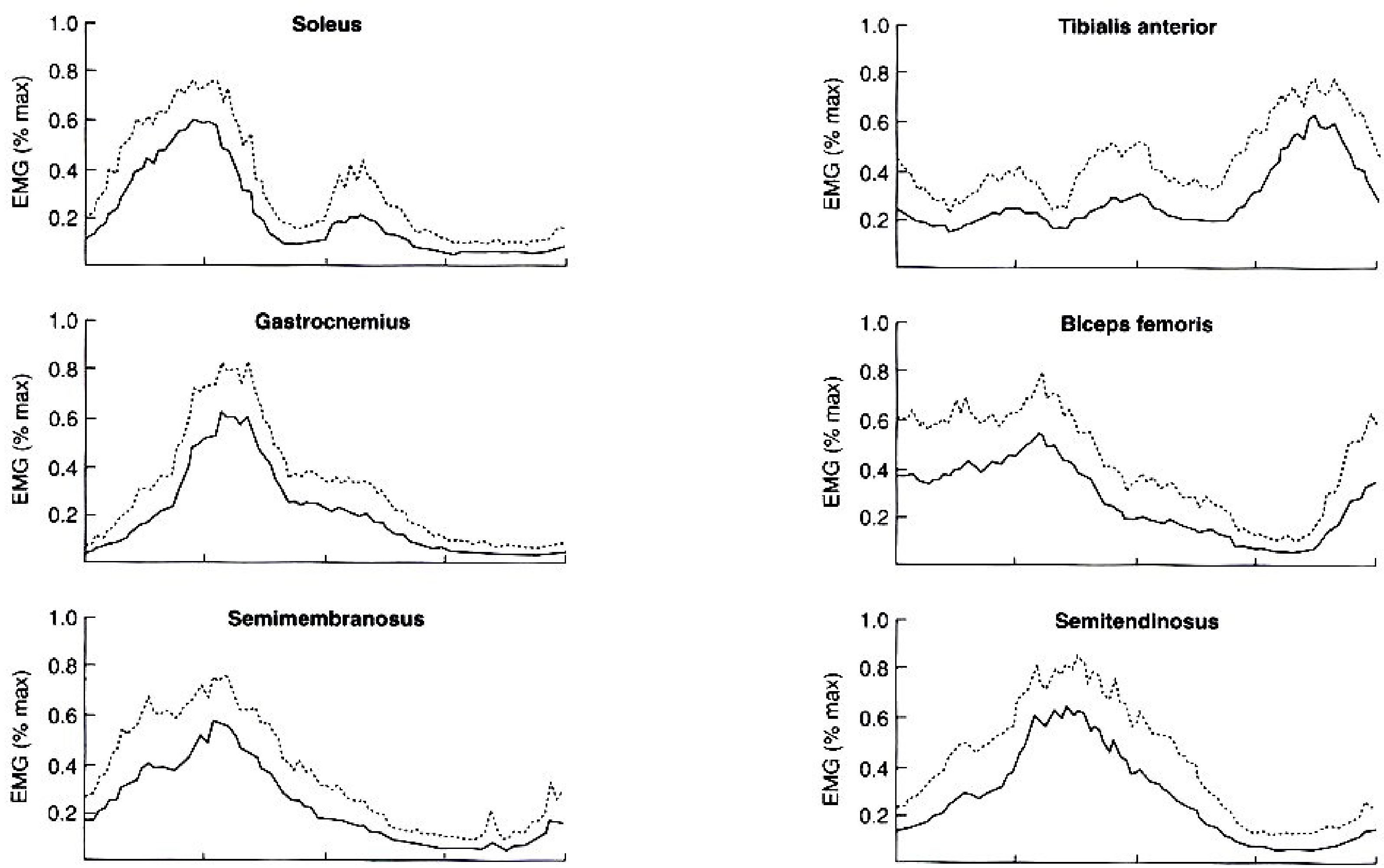
Broker (2003)

FIGURE 5.8 Clock diagrams illustrating the *(a)* measured, *(b)* natural (nonmuscular), and *(c)* muscular components of pedal loading for an elite U.S. National Team cyclist. The muscular and natural components sum to create the measured load. The natural component is derived from the inertial and gravitational effects present during pedaling, and thus arises at no cost to the rider.



1. Tibialis Anterior
2. Soleus
3. Gastrocnemius
4. Vastii
5. Rectus Femoris
6. Short Head of Biceps Femoris
7. Two joint Hamstrings
8. Iliacus
9. Gluteus Maximum

Prilutsky and Gregor (2000)


Soleus
Tibialis anterior
Gastrocnemius
Biceps femoris
Semimembranosus
Semitendinosus
EMG (% max)
1.0
0.8
0.6
0.4
0.2

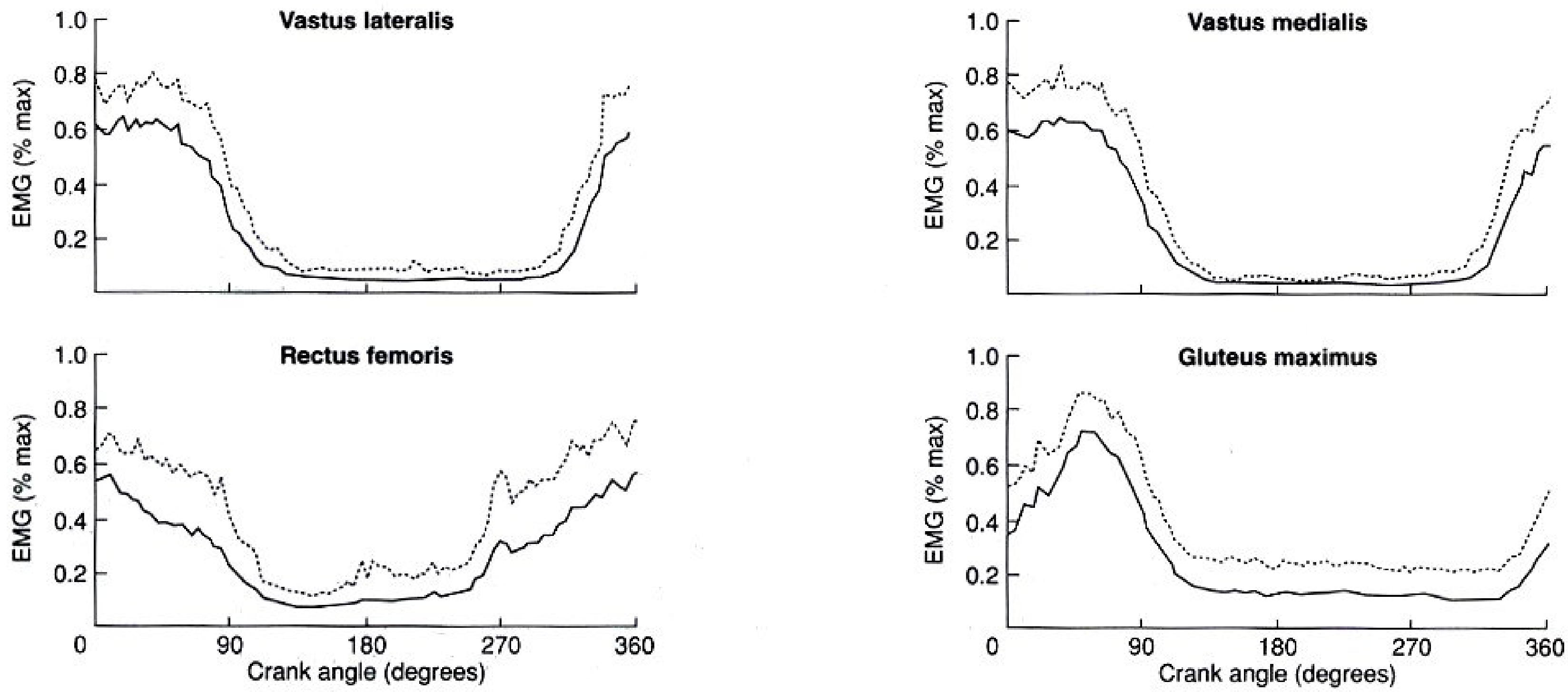
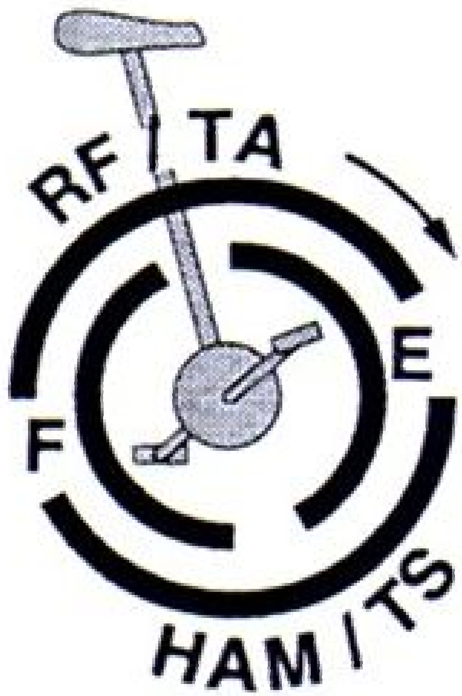
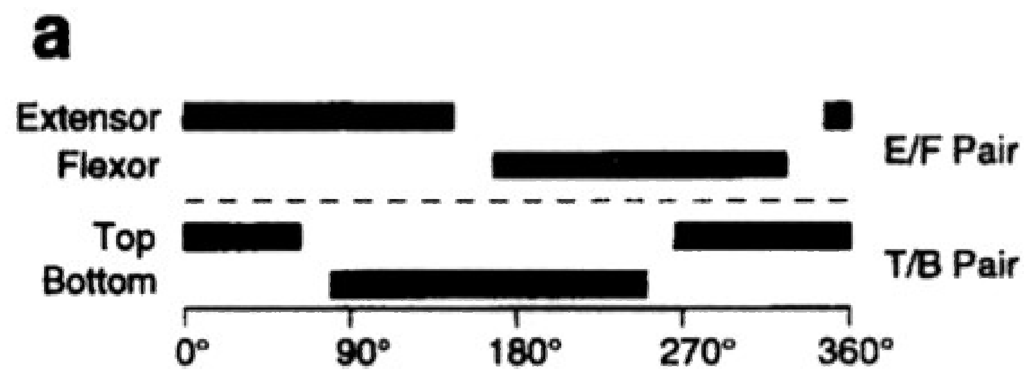
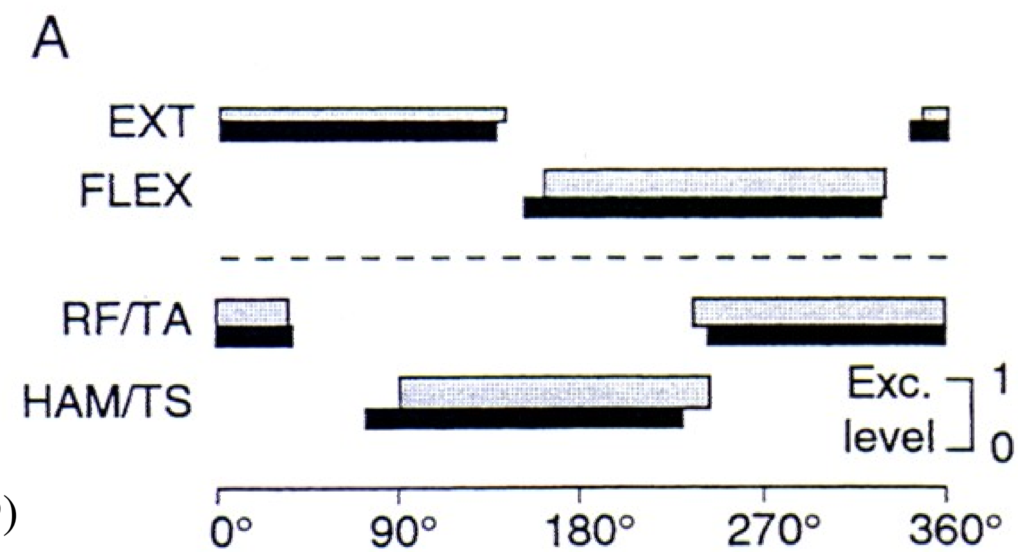


Fig. 1.8 Average patterns of muscle activation during the pedalling cycle for 10 muscles in the human lower extremity. The solid line is the average pattern of 15 pedalling cycles across 18 subjects (270 cycles) and the dashed curve is 1 s.d. above the mean. Magnitudes are normalized to maximal activation. Reproduced with permission from Ryan and Gregor (1992).





Raasch et al. (1996)



Raasch & Zajac (1999)

Muscle recruitment strategy

The nervous system adjusted the motor programs in order to compensate for changes of the effector organ characteristics.

Hence the muscle recruitment in cycling might change due to fatigue.

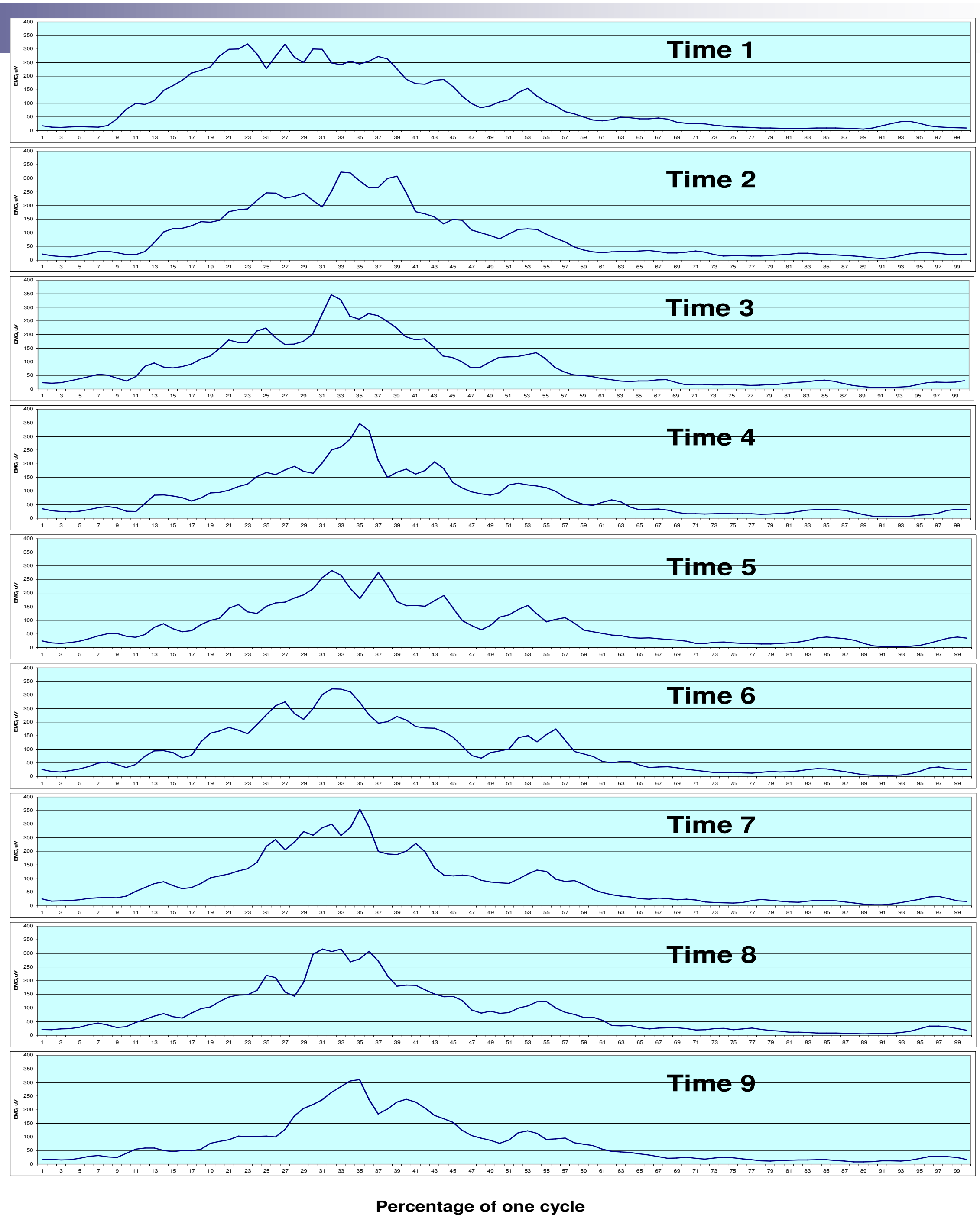
- SRM Cycling ergometer (SRM, Germany)
- Rode at 95% VO2max power for 5 minutes

Maximal cycling exercise for 5 min. at 90 rpm on an isokinetic cycling ergometer (SRM)

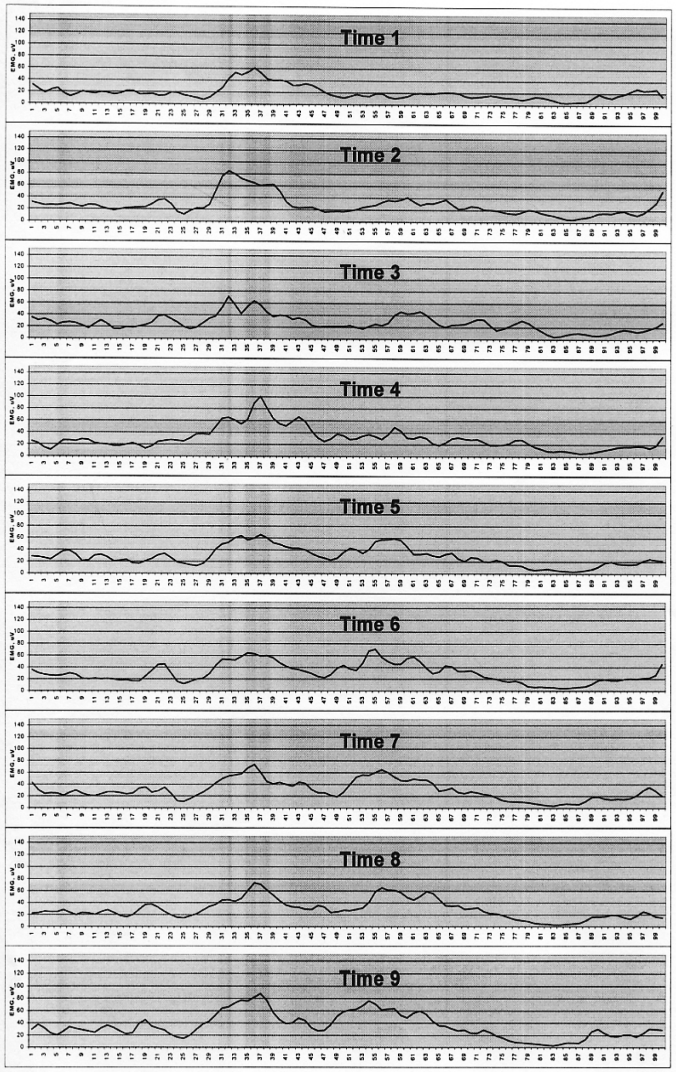
Med. Gastro

Lag :

T2	2
T3	0
T4	5
T5	6
T6	3
T7	4
T8	3
T9	8



[redacted] Biceps



	Area	Peak
Time 1	2008.5	60.9
Time 2	2775.4	84.6
Time 3	2671.9	71
Time 4	2976.1	100.4
Time 5	2878.5	65.4
Time 6	3038.9	70.7
Time 7	2989.1	73.6
Time 8	2908.9	73.3
Time 9	3534.7	87.8

Percentage of one cycle

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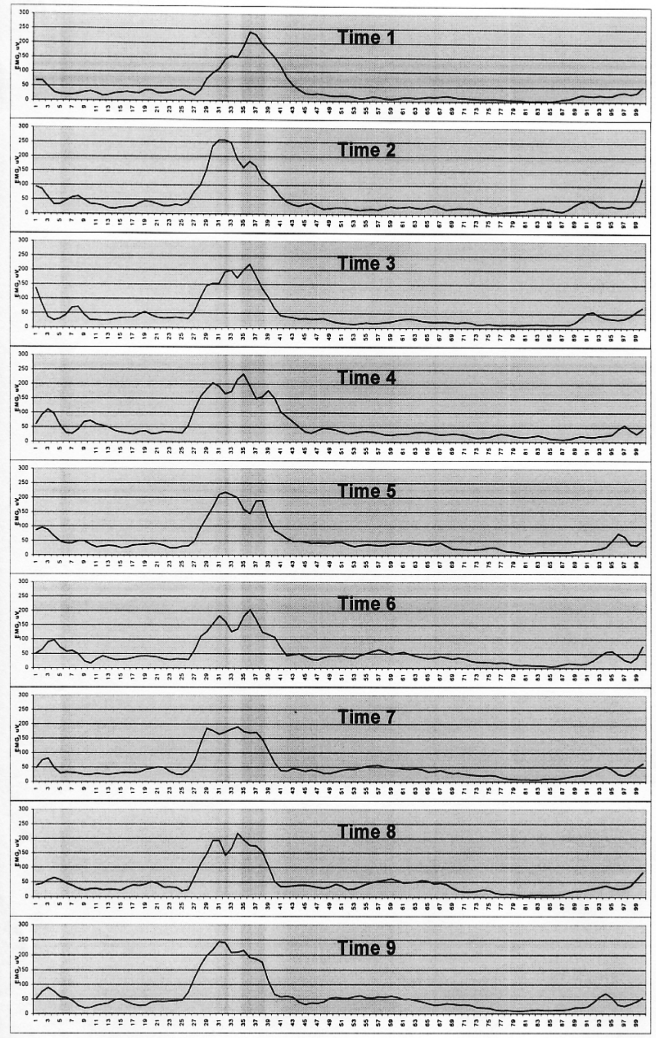
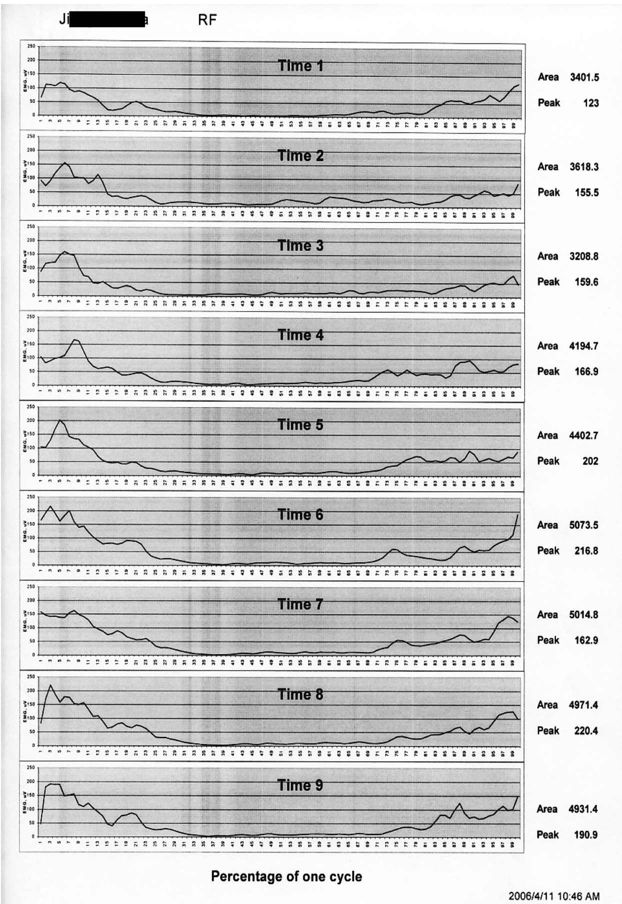
[redacted] Semitend



	Area	Peak
Time 1	3932.9	238.3
Time 2	4927.2	257.1
Time 3	4654.9	220
Time 4	5537.1	234.6
Time 5	5204.2	217.9
Time 6	5112.2	203.5
Time 7	5003.2	190.1
Time 8	4900.9	217.3
Time 9	5905	243.9

Percentage of one cycle

2006/4/10 06:22 PM


[redacted]
RF
Time 1
Area 3401.5
Peak 123
Time 2
Area 3618.3
Peak 155.5
Time 3
Area 3208.8
Peak 159.6
Time 4
Area 4194.7
Peak 166.9
Time 5
Area 4402.7
Peak 202
Time 6
Area 5073.5
Peak 216.8
Time 7
Area 5014.8
Peak 162.9
Time 8
Area 4971.4
Peak 220.4
Time 9
Area 4931.4
Peak 190.9
Percentage of one cycle
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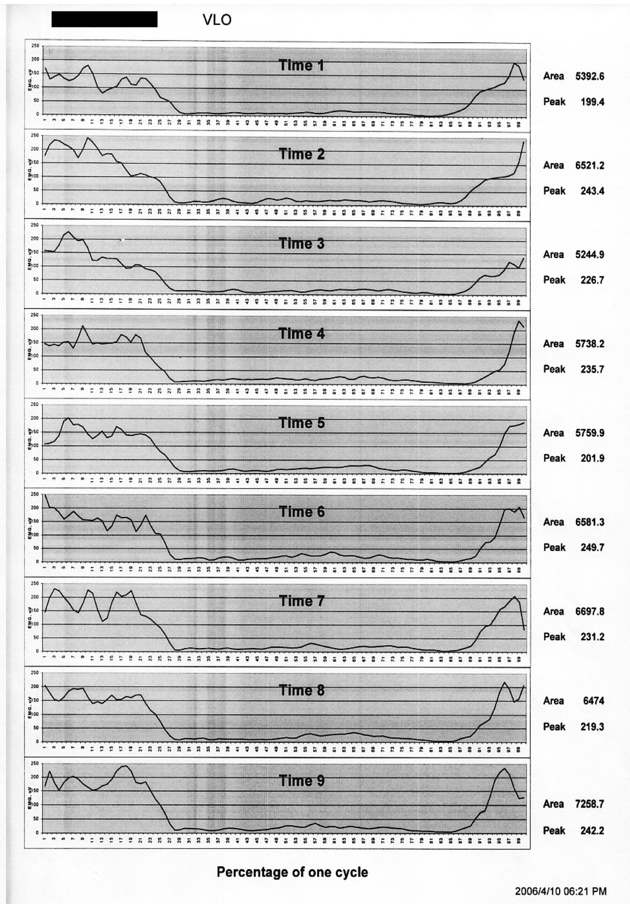
[redacted]
VLO
Time 1
Area 5392.6
Peak 199.4
Time 2
Area 6521.2
Peak 243.4
Time 3
Area 5244.9
Peak 226.7
Time 4
Area 5738.2
Peak 235.7
Time 5
Area 5759.9
Peak 201.9
Time 6
Area 6581.3
Peak 249.7
Time 7
Area 6697.8
Peak 231.2
Time 8
Area 6474
Peak 219.3
Time 9
Area 7258.7
Peak 242.2
Percentage of one cycle
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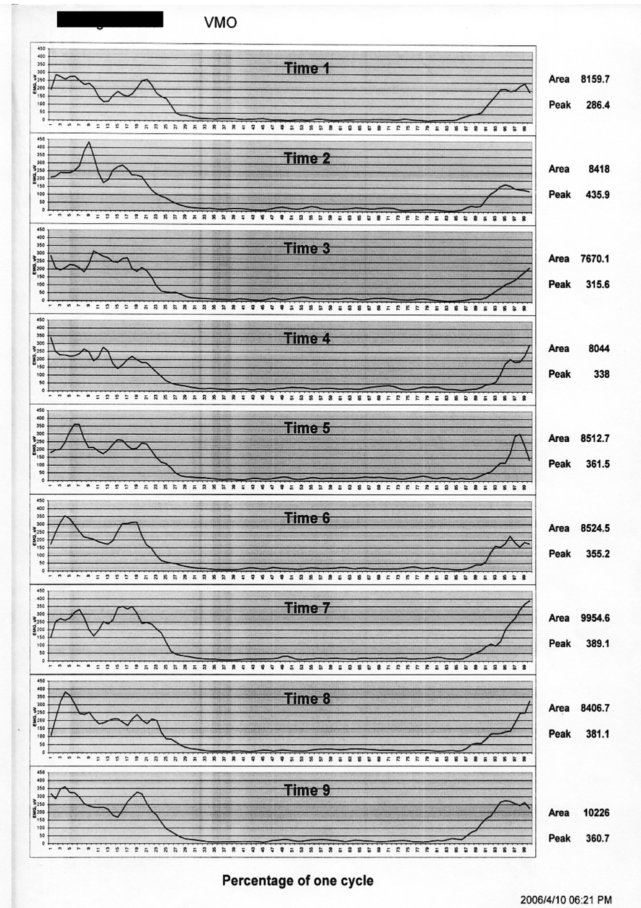
[redacted]
VMO
Time 1
Area 8159.7
Peak 286.4
Time 2
Area 8418
Peak 435.9
Time 3
Area 7670.1
Peak 315.6
Time 4
Area 8044
Peak 338
Time 5
Area 8512.7
Peak 361.5
Time 6
Area 8524.5
Peak 355.2
Time 7
Area 9954.6
Peak 389.1
Time 8
Area 8406.7
Peak 381.1
Time 9
Area 10226
Peak 360.7
Percentage of one cycle
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