Energetics in Canoe Sprint

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“Stay hungry, stay foolish”

(*Steve Jobs, 1955-2011*)

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Abbreviations

A		adult
A_0, A_1, A_2		exponential terms of oxygen uptake kinetics
A_0'		assigned value for exponential terms of oxygen uptake kinetics
ATP		adenosine triphosphate
AUS		Australia
C	[kJ/m]	energy cost of locomotion
CAN		Canada
E		on ergometer
E_{AER}	[kW]	power produced by aerobic system
E_{BLC}	[kW]	power produced by anaerobic lactic system
E_{PCR}	[kW]	power produced by anaerobic alactic system
ESP		Spain
E_{TOT}	[kW]	power produced by all the three energy systems
F		female
FRA		France
G		group
GBR		Great Britain
GDX		graded exercise
ICF		International Canoe Federation
ITA		Italy
J		junior
LT		lactate threshold
M		male
MAOD		maximal accumulated oxygen deficit
MLSS	[mM]	maximal lactate steady state
MK1-1000		men's kayak single 1000 m
NZL		New Zealand
O_2		oxygen
OD	[l/min]	oxygen deficit
Pcr-La-O_2		phosphocreatine-lactate-oxygen
R.Q.		respiratory quotient
RSA		South Africa
SWE		Sweden
TD_1,TD_2	[s]	time delays of oxygen uptake kinetics

VCO_2	[l/min]	expired carbon dioxide
VE	[l]	minute ventilation
VO_2	[l/min] or [ml/min]	oxygen uptake
$VO_2(b)$	[l/min]	rest baseline value of VO_2
$VO_2(t)$	[l/min]	oxygen uptake at a certain time
VO_{2max}	[l/min]	maximal oxygen uptake
VO_{2PCR}	[l/min]	fast component of oxygen debt
VO_{2peak}	[l/min] or [ml/min/kg]	peak oxygen uptake
W		on water
W_{AER}	[kJ]	aerobic energy supply
$W_{AER}\%$	[%]	relative aerobic contribution
$W_{AER}N$	[kJ/kg]	normalized aerobic energy supply
W_{BLC}	[kJ]	anaerobic lactic energy supply
$W_{BLC}N$	[kJ/kg]	normalized anaerobic lactic energy supply
WK1-500		women’s kayak single 500 m
W_{PCR}	[kJ]	anaerobic alactic energy supply
$W_{PCR}N$	[kJ/kg]	normalized anaerobic alactic energy supply
W_{TOT}	[kJ]	total energy supply
$W_{TOT}N$	[kJ/kg]	normalized total energy supply
τ_0, τ_1, τ_2	[s]	time constants of oxygen uptake kinetics

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1 Introduction

1.1 Background

Canoe sprint has a long history in Olympic Games, since its debut in 1936. For over 70 years, the performance level of this sport has shown tremendous improvements, as indicated by race result. This improvement could be attributed to a variety of factors. Among them, the physiological knowledge of this sport has played a significant role because this knowledge was the basis for establishing the training philosophy.

The investigation on the physiology of canoe sprint dates back as early as the 1970s, when tests were performed either on a modified Monark cycling ergometer (PYKE ET AL., 1973) or on open water with the Douglas gas analysis technique (TESCH ET AL., 1976). However, the direct investigation on the energetic profile of the canoe sprint was not found until 1997, when the relative aerobic contributions (W_{AER} %) in three simulated racing distances (200 m, 500 m, and 1000 m) of canoe sprint tested on an ergometer were provided using the energy calculating method of maximal accumulated oxygen deficit (MAOD). More recently, the energetic profile of the canoe sprint was further investigated under various conditions, including with different energy calculating methods, paddling conditions, and with paddlers of different performance levels. These direct findings consistently indicated an underestimation of W_{AER} % in canoe sprint when compared to the commonly cited table originally given by Astrand and Rodahl (1970). Nonetheless, the reported W_{AER} % in the canoe sprint varies among different studies. For example, the W_{AER} % varies from 29 % to 40 % (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008) and from 57 % to 69 % (BISHOP, 2000; BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008; ZAMPARO ET AL., 1999) in 40 s and 120 s maximal padding. A number of factors were suspected to influence the results, including energy calculating methods, paddling condition (on water vs. on ergometer), performance level of paddlers, motivation, muscle fiber composition, etc.

With regard to W_{AER} %, it has been summarized from a large number of relevant investigations that W_{AER} % enhanced exponentially with the duration of high-intensity exercises (GASTIN, 2001). The duration threshold between aerobic dominance (W_{AER} % > 50 %) and anaerobic dominance (W_{AER} % < 50 %) was approximately 75 s, according to the exponential regression function (GASTIN, 2001), which was shorter than the previous description (2 min (ASTRAND & RODAHL, 1970)). However, this function was drawn from the relevant investigations with different methods of energy calculation, as well as of different movement patterns. These two possible influencing factors should be investigated before extending the findings with one method of energy calculation and one movement pattern to others, the result of which would decide whether the findings from the energetics of canoe sprint could be useful for other sports with similar duration.

In addition, other aspects of the energetic profile in one sport include the maximal lactate steady state (MLSS) and the energy cost (C). MLSS corresponds to the highest workload that can be maintained over time without a continuous blood lactate accumulation (BENEKE, 1995; HECK ET AL., 1985). C is defined as the amount of energy above the resting level spent per unit of distance (CERRETELLI & DI PRAMPERO, 1990). However, it was demonstrated that MLSS seemed to depend on the involved muscle mass in the given movement patterns (BENEKE, 2003b). Few studies were found with the emphasis on MLSS in kayaking. Although C varies in different locomotion such as swimming (CAPELLI ET AL., 1998), running (DI PRAMPERO, 1986), and cycling (DI PRAMPERO, 1986), it is still unclear whether the C in canoeing is similar to that in kayaking.

1.2 State of the Problem

Although the energetics of canoe sprint have been well documented, there are still special issues in this area that need to be clarified. The possible factors influencing the energetic profile in canoe sprint are supposed to be excluded, or found out, to explain the variation between the findings in previous studies. Then, the possible influence of movement patterns on the exponential correlation between W_{AER} % and the duration of high-intensity exercise are in need of support from comparative investigation of the energetic profile in different movement patterns, including kayaking and canoeing. Further, some special issues of energetic profile in canoe sprint (e.g., C and MLSS) also require study.

1.3 Purpose of this Study

Therefore, this study aimed to investigate first the possible factors associated with W_{AER}% in kayaking. With the findings from the first step, the energetic profiles of kayaking and canoeing would be investigated with controlled performance conditions. The exponential correlation between W_{AER}% and the duration of high-intensity exercise would be resummarized from relevant literature according to the method of energy calculation. The possible influence of method of energy calculation as well as the movement pattern would be verified with subjects from canoe sprint and other sports in order to support the exponential correlation between W_{AER}% and the duration of high-intensity exercise. Last, C in canoeing and MLSS in kayaking would also be investigated (Figure 1-1).

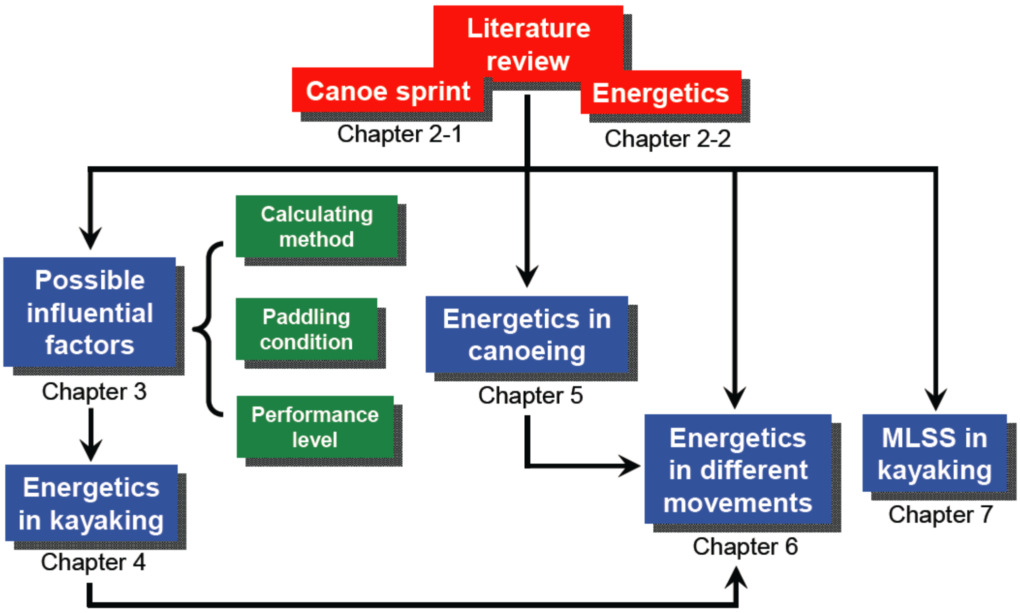

Figure 1-1: Illustration of the research design

1.4 Research Questions

This study was devoted to clarifying the following issues:

I. Do methods of energy calculation, paddling condition (on water vs. on ergometer), and performance level of paddlers (adult vs. junior) have influence on W_{AER} % in kayaking?

II. How much are the energy contributions, especially W_{AER} %, in kayaking and canoeing?

III. Does W_{AER} % depend on the movement pattern during high-intensity exercises with the same duration?

IV. How is the C of canoeing?

V. How is the MLSS in kayaking?

2 Literature Review

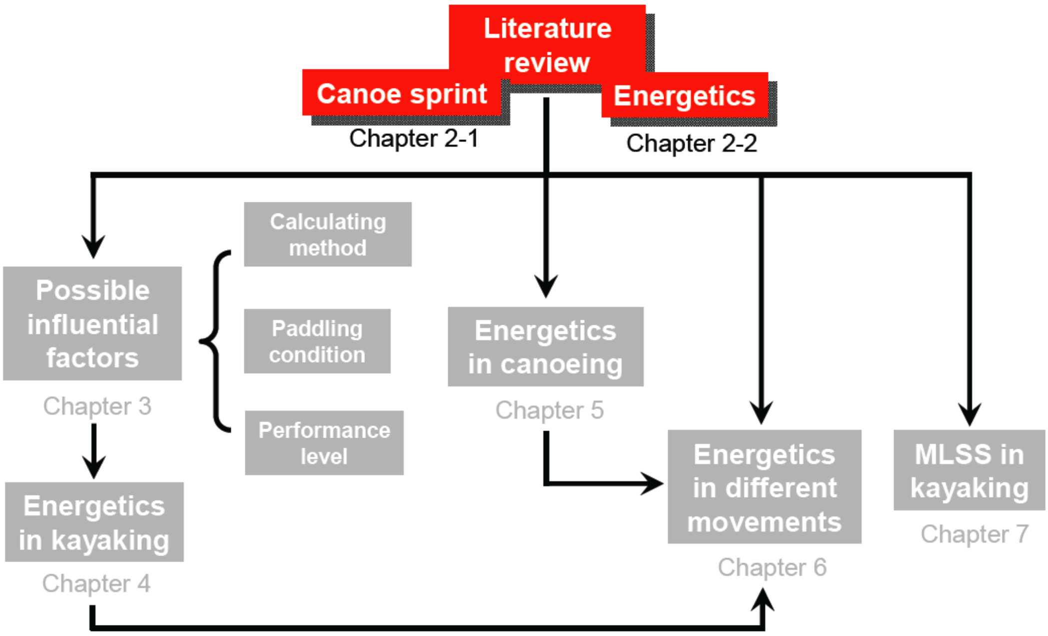

Illustration of the research design - Chapter 2

2.1 Development of Race Result in Canoe Sprint

2.1.1 Introduction

Olympic canoe sprint consists of canoe sprint and kayak sprint. Since its debut as an Olympic sport in 1936, four distances (500 m, 1000 m, 10,000 m, and 200 m) have been contested. The 10,000 m was cancelled in 1960, and 200 m become a new race distance in 2009. Now, 12 disciplines are contested in Olympic canoe sprint. The finishing time of the six single disciplines during the 2012 Olympic Games were 210.1 s (kayak men 1000 m), 222.1 s (canoe men 1000 m), 113.2 s (kayak women 500 m), 36.8 s (kayak men 200 m), 43.4 s (canoe men 200 m), and 45.5 s (kayak women 200 m).

During the past 70 years, 500 m and 1000 m were the two canoe sprint distances contested in the Olympic Games. The race results of these two distances in Olympic Games and world championships throughout the history of the sport could provide some information about its development. Figure 2-1 is a description of the race results of men’s kayak single 1000 m (MK1-1000) and women’s kayak single 500 m (WK1-500) from 1948 to 2013. The race results of MK1-1000 and WK1-500 have increased 32.5 % and 42.1 %, respectively, which means a corresponding 5.0 % and 6.5 % increase in each decade, and a 2.0% and 2.6% increase in each Olympic cycle, respectively. This development could be attributed to all of the possible factors, such as anthropometry, physiology, equipment, training, and diagnostics.

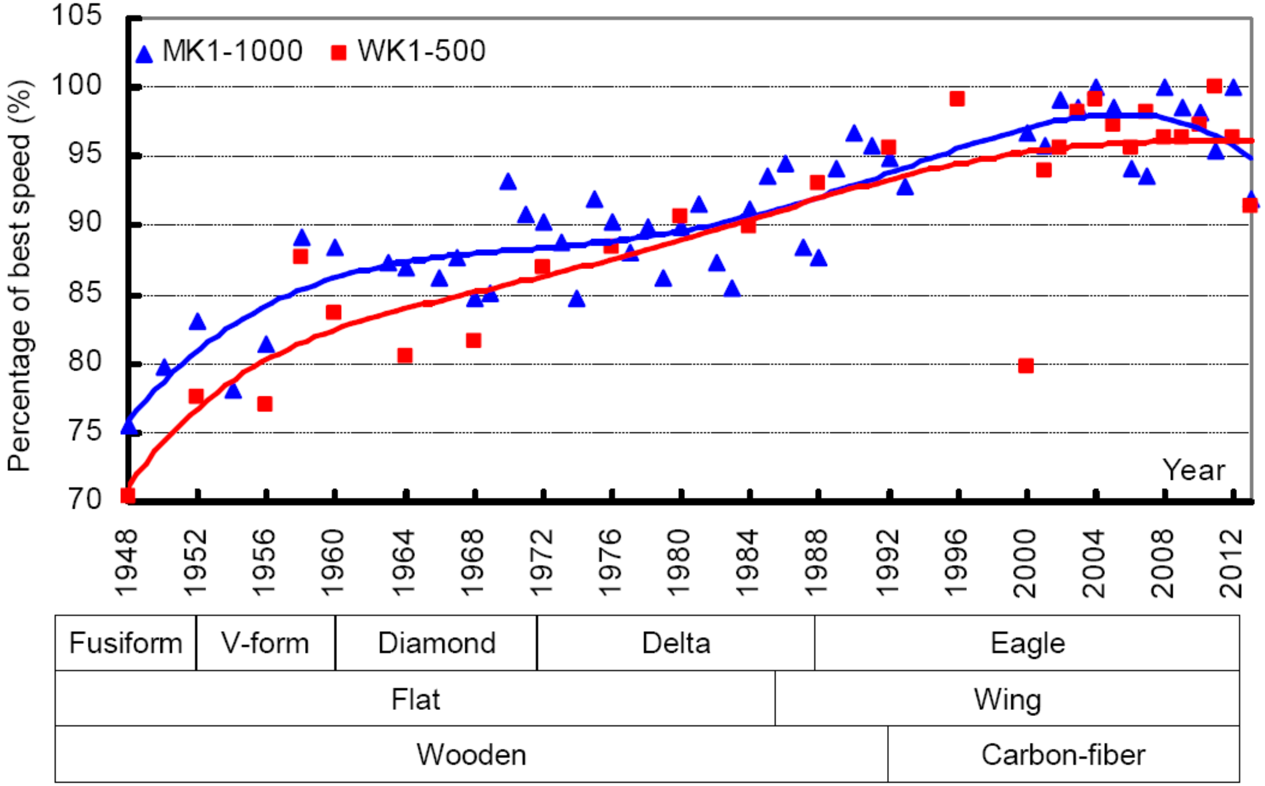

Figure 2-1: Race results of men's kayak single 1000 m (MK1-1000) and women's kayak single 500 m (WK1-500) in Olympic Games and world championships from 1948 to 2013 (bottom is the development of boat form, paddle form, and boat material; raw data see Appendix 1)

2.1.2 Anthropometry

Canoe sprinters have gotten taller and stronger during the past decades, along with the anthropometric development of population, which might be the first reason for the development of race result in this sport. Table 2-1 is a summary of some anthropometric and physiological characteristics of canoe sprinters in various national teams as reported in the literature. As in Table 2-1, international male kayakers were characterized with a height of >180 cm and a body mass of >80 kg. For example, the average height and body mass in Spanish and British male kayakers were 183 cm and 86 kg (GARCIA-PALLARES, GARCIA-FERNANDEZ, ET AL., 2010), 183 cm and 85 kg (VAN SOMEREN & PALMER, 2003), respectively. Additionally, some even taller paddlers did exist in some national teams.

Although general anthropometric characteristics could be provided in Table 2-1, the development of anthropometry in world canoe sprinters could still not be found because of the variation of performance level among these national teams. More reliable information about the developing trend of anthropometry would be possible if a large volume of data from international paddlers were gathered. Figure 2-2 is a summary of the height and body mass of male paddlers in several Olympic Games, in which a trend of increase is demonstrated. The increase of Olympic paddlers was in line with the trend in population. As reported by Cole, the height of most of the European adult population has increased 10–30 cm each decade since the 19^{th} century (COLE, 2000), which means that it has been possible to recruit taller and stronger paddlers. Based on the data from ergometric testing with similar test protocols in Table 2-1, a correlation function could be drawn:

$$Y = 0.5798 * e^{0.0249*x}.$$

Among them, y is the VO_{2peak}; x is body mass; and e is the natural logarithm (Figure 2-3). The figure reveals the positive correlation between body mass and VO_{2peak} in international paddlers. Therefore, anthropometric increase could be one of the causes of the development of race results in canoe sprint during the past decades.

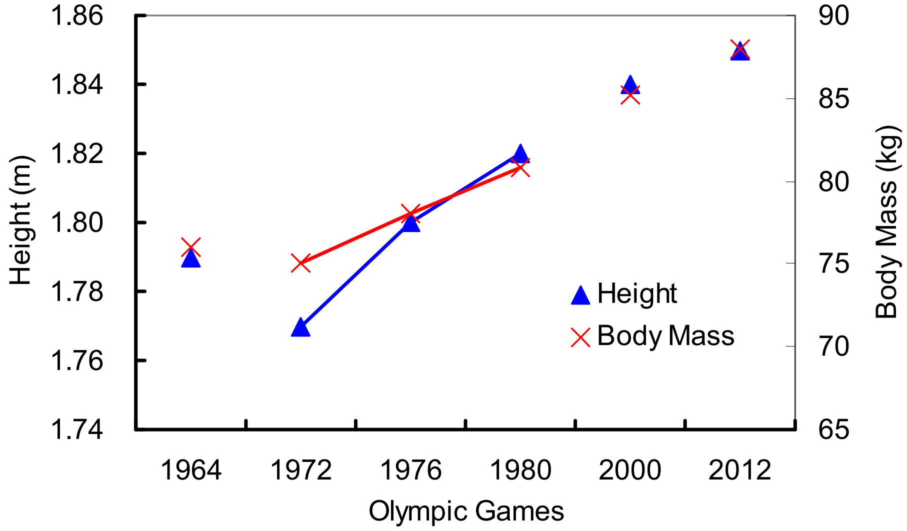

Figure 2-2: Summary of the height and body mass of male paddlers in several Olympic Games (ACKLAND ET AL., 2003;COX, 1992; LI, 2012; SHEPHARD, 1987), raw data see Appendix 2

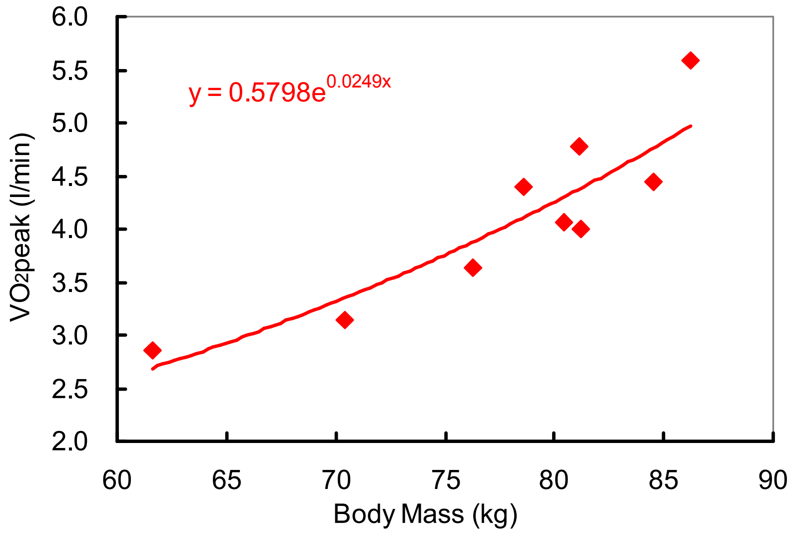

Figure 2-3: Correlation between body mass and VO_{2peak} (Data from Table 2-1; data of VO_{2peak} from incremental test on kayak ergometer, raw data see Appendix 3)

Table 2-1: Summary of some anthropometric and physiological characteristics of canoe sprinters in various national teams

Literature	Country	N	Age	Height	Body Mass	Body Fat	VO_{2peak}
			[yrs]	[m]	[kg]	[%]	[l/min]
Men's Kayak							
(TESCH ET AL., 1976)	SWE	4	25				5.40 ± 0.34[A,1]
							4.61 ± 0.26[B,1]
(TESCH & LINDEBERG, 1984)	SWE	7	20 ± 1.1	1.86 ± 0.04	82.4 ± 3.9	5.4 ± 1.1[§]	5.40 ± 0.24[A,2]
(FRY & MORTON, 1991)	AUS	7	26 ± 7.1	1.8 ± 0.05	81.1 ± 10.3		4.78 ± 0.60[D,3]
(BILLAT, FAINA, ET AL., 1996)	FRA	9	21 ± 5.1	1.78 ± 0.07	75.2 ± 10.5		4.03 ± 0.62[B,4]
(PEREZ-LANDALUCE ET AL., 1998)	ESP	8	22 ± 1.6	1.82 ± 2.9	81.3 ± 2.3		5.01 ± 0.38[C,5]
(BISHOP ET AL., 2003)	AUS 500 m	7	24 ± 4		80.4 ± 5.6		4.07 ± 0.52[D,6]
(VAN SOMEREN & PALMER, 2003)	GRB 200 m	13	26 ± 5	1.83 ± 0.06	84.5 ± 4.9	14.1 ± 2.9[#]	4.45 ± 0.55[D,7]
(KROFF, 2005)	RSA	11	26 ± 6	1.83 ± 0.07	78.6 ± 6.9	11.6 ± 3.5[○]	4.40 ± 0.3[D,4]
(BONETTI ET AL., 2006)	NZL	10	23 ± 8.3	1.8 ± 0.04	81.2 ± 7.2		4.00 ± 0.5[D,8]
(FORBES & CHILIBECK, 2007)	CAN	10	20 ± 2.3	1.79 ± 0.05	76.3 ± 10.6		3.64 ± 0.43[D,5]
							3.38 ± 0.60[B,5]

(GARCIA-PALLARES, GARCIA-FERNANDEZ, ET AL., 2010)	ESP	11	26 ± 2.8	1.83 ± 0.07	86.2 ± 5.2		5.59 ± 0.03[D,9]
(BUGLIONE ET AL., 2011)	ITA	46	18 ± 2.7	1.81 ± 0.06	78.2 ± 6.1		4.79 ± 0.35[E,10]
Men's Canoe							
(BUGLIONE ET AL., 2011)	ITA	5	22 ± 5.5	1.77 ± 0.02	76.8 ± 3.5		4.75 ± 0.45[E,10]
Women's Kayak							
(TESCH & LINDEBERG, 1984)	SWE	4	20 ± 0.9	1.7 ± 0.08	66.5 ± 3.6		3.60 ± 0.25[A,2]
(BISHOP, 2000)	AUS	9	23 ± 5	1.7 ± 0.06	70.4 ± 6.3	22.1 ± 6.0[○]	3.15[D,6]
(FORBES & CHILIBECK, 2007)	CAN	5	18 ± 2.4	1.64 ± 0.06	61.6 ± 5.2		2.86 ± 0.23[D,5]
							2.65 ± 0.40[B,5]
(BUGLIONE ET AL., 2011)	ITA	23	18 ± 2.5	1.72 ± 0.06	66.0 ± 6.6		3.45 ± 0.31[E,10]

[A] treadmill; [B] incremental test with arm cranking; [C] not mentioned; [D] incremental test on kayak ergometer; [E] incremental test on water; [1] Douglas bag; [2] not mentioned; [3] Morgan ventiometer; [4] K2, Cosmed, ITA [5] MMC 4400 tc system, SensorMedics, CA; [6] Ametek, SOV S-3A and COV CD3A, PA; [7] Oxycon Alpha, NED; [8] MetaMax 3B, Cortex, GER; [9] Jaeger Oxycon Pro system, Ger; [10] K4b2, Cosmed, ITA; [§] three sites skinfold; [#] four sites skinfold; [○] seven sites skinfold.

2.1.3 Physiology

While the anthropometric increase of canoe sprinters during the past decades resulted in some changes in their physiological characteristics, a better understanding of the physiological characteristics in canoe sprint could also contribute to the development of the race results. Extensive investigations on the physiology of canoe sprint did not exist until the 1970 s. In 1976, VO_{2peak} in canoe sprinters was reported for the first time ever with a value of 5.4 l/min on the treadmill. The blood lactate after 500 m and 1000 m maximal paddling was 13.2 mM and 12.9 mM, respectively (TESCH ET AL., 1976). However, resulting from the lack of the technique in using portable spirometry on water and the lack of a reliable canoe/kayak ergometer, the physiological knowledge of canoe sprint was limited before the 1990 s.

Among the physiological characteristics in canoe sprint, knowledge of energy contribution in competition is of significant importance. Prior to the 1990 s, knowledge of energy contribution in canoe sprint was indirectly from investigations on other sports. According to the table provided by Astrand and Rodahl in 1970, 50 % of the energy supply during 2 min maximal exercises with involvement of large muscles was from the aerobic metabolic pathway (ASTRAND & RODAHL, 1970). This table can still be found in current textbooks (ASTRAND ET AL., 2003;HOLLMANN & STRUEDER, 2009). Accordingly, the W_{AER} % of 500 m and 1000 m canoe sprint, in which the finishing time are approximately 2 min and 4 min, were approximately 50 % and 70 %. However, the first investigation on energy contribution in canoe sprint with a canoe/kayak ergometer indicated that the W_{AER} % in maximal 2 min and 4 min paddling were > 60 % and > 80 % (BYRNES & KEARNEY, 1997). This means that the data provided by Astrand and Rodahl underestimated the W_{AER} % in maximal exercises, including canoe sprint. Since W_{AER} % was such basic physiological knowledge, an underestimation of W_{AER} % could lead to an insufficiency of aerobic endurance training. However, although there were few direct investigations on energy contribution in canoe sprint before the end of the 1990 s, the importance of aerobic capacity in canoe sprint might be found during the training practice of this sport (KAHL, 1997), as well as of other sports such as rowing (MADER & HOLLMANN, 1977). At least since the beginning of the 1990 s, the German canoe sprinters have trained with >75 % of their water training volume in the aerobic-intensity zone (ENGLERT & KIESSLER, 2009; KAHL, 1997). Consequently, it could be speculated that the renewed knowledge on aerobic energy contribution in canoe sprint leads to an emphasis on aerobic capacity during training, which may have also contributed to the development of race results during the past decades.

2.1.4 Equipment

Revolutionary development in the race result of canoe sprint during the past decades is due to the improvement of equipment design in canoe sprint. As illustrated at the bottom of Figure 2-1, improvement of equipment design happened primarily in three aspects, including boat form, paddle form, and material of boat. The carbon fiber boat has been widely used in international competitions since 1990, but before that the boat was made of wood. The advantage of carbon fiber compared to wood as a boat material was not found in reports. In contrast, the invention of the “wing” paddle by the Swedish in the 1980 s brought a huge leap to the race results in canoe sprint (JACKSON ET AL., 1992). Compared to the former flat paddle, “wing” paddle is reported to increase the area of paddle vortex, to generate the forward lift force, and therefore, to increase the blade efficiency from 72 % to 88 % (JACKSON ET AL., 1992).

Compared to the improvement of boat material and paddle form, the form of the boat experienced a more frequent alteration, which contributed much more to the development of the race results. With the introduction of the V-form boat in the 1952 Helsinki Olympics, the winning time by Gert Fredriksson was improved by 25.3 s. When a newly invented diamond boat was used in the next Olympics, Gert Fredriksson enhanced his finishing time again by 16.9 s, but won only a bronze medal. However, the Danish athlete Erik Hansen participated in four Olympics in a row, from 1960 to 1972, with the same diamond boat, but with an improvement of less than 1 s (ROBINSON ET AL., 2002).

Some other aspects of alteration in equipment design included the beam of boat and the seat in kayak boat (MICHAEL ET AL., 2009). The beam was fixed to the minimum limit by the International Canoe Federation (ICF) before

2000. Since the removal of this limit, new boats with smaller beams have been manufactured. Although the narrower boats put a higher demand on the stability of paddlers, they can decrease the water resistance during paddling. In 2004, the swivel seat in the kayak boat was again allowed by the ICF. It was reported that it allowed a higher leg-push force and a higher range of motion in the knee on kayak ergometer (PETRONE ET AL., 2006). However, the swivel seat would demand a higher level of balance when paddling on water, which is why its application is still under debate.

Table 2-2: Examples of old and new equipment in canoe sprint

	Kayak Boat/Paddle	Canoe Boat/Paddle	Kayak Seat
Old	a 	b 	c 
New	d 	d 	e 

a: http://www.flickr.com/photos/blufftonlibrary/469923044/in/photostream/
b: http://www.americancanoe.org/?page=legends
c: http://www.nelo.eu/shop/en/racing/seats.html
d: http://www.tsn.ca/summer_sports/story/?id=396289
e: http://www.zimbio.com/pictures/WhfteciBSEk/Olympics+Day+10+Canoe+Sprint/LAXJQRzL463
e: http://www.nelo.eu/shop/en/racing/seats.html

Table 2-2 is a summary of some examples of old and new equipment during the past decades. It indicates the advancement in boat material, boat form, paddle form, beam of boat, as well as kayak seat. Conclusively, the advancement in the equipment might have played a significant role in the development of race results during the past decades.

2.1.5 Training

With regard to training, solid support could not be provided from longitude studies, but some case reports were found to explain the development of race results during the past decades. The legendary athlete in world canoe sprint Birgit Fischer was reported to have trained with a volume as high as 1300 h in late 1970 s, in which the specific volume was 600–800 h. Her contemporary canoeist Olaf Heukrot had a similar training volume (LENZ, 1994). However, when Birgit Fischer retrained for the 2004 Olympic Games, her yearly training volume was only 359 h, with 228 h specific training (FISCHER, 2006). Some other training documentation revealed a volume of 900 h in 1989/1990 in the German national team (KAHL, 1997), and a volume of 710 h in 2005/2006 in the Chinese national team coached by former German head coach Josef Capousek (2009). Additionally, Issurin reported a decrease of training volume from 1100 h in the 1980 s to 900 h in the 1990 s (ISSURIN, 2008). A Finnish canoeist was reported to have a yearly training volume of 6000 km in the 1980 s (胡松楠, 1989). Comparatively, the Spanish national team had a yearly volume of 4415 km on water during the preparation for the 2008 Olympic Games, with an additional volume of 109.6 h in strength training (GARCIA-PALLARES ET AL., 2010). As illustrated in Figure 2-4, there seemed to be a trend of decrease in training volume during the past decades, and yearly the training volume in the new century was approximately 700–800 h.

The high training volume before the 1990 s might have resulted from the politicization of sport in the former East Germany and Soviet Union, where the athletes could train full-time (personal communication), with the support of doping, with which more volume could be sustained by athletes, and from the method of training documentation, with which the training volume might have been documented as more than the actually trained volume. However, those factors have become less possible since the 1990 s. High-quantity (volume) training been replaced by high-quality training done in a more scientific way, (e.g., more emphasis on aerobic capacity and aerobic endurance training as mentioned above).

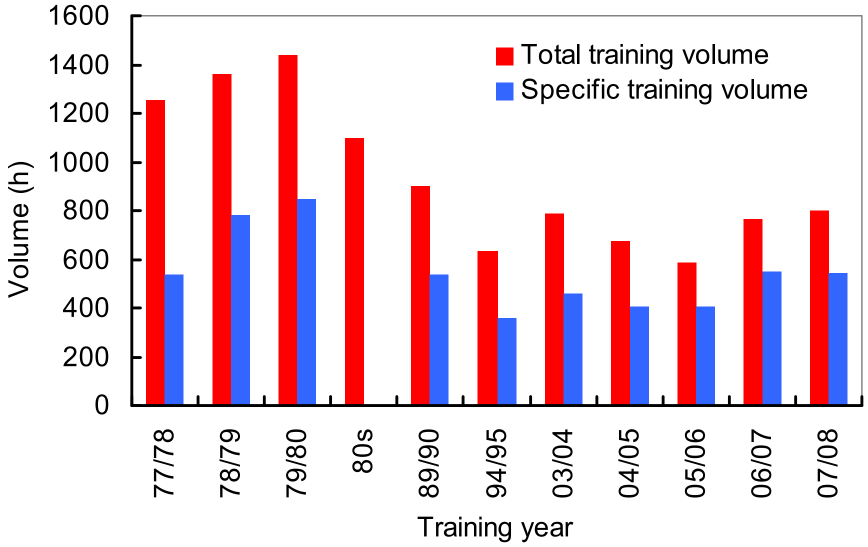

Figure 2-4: Yearly training volume based on case reports (77/78, 78/79, 79/80 (LENZ, 1994); 80 s (ISSURIN, 2008); 89/90, 94/95 (KAHL, 1997); 03/04 (FISCHER, 2006); 04/05 (CAPOUSEK, 2009); 05/06, 06/07, 07/08 (ENGLERT & KIESSLER, 2009)), raw data see Appendix 4

2.1.6 Diagnostics

Diagnostics in canoe sprint have not been as early and extensive as in other sports (e.g. rowing), but, doubtlessly, the importance of physiological and biomechanical diagnostics for the development of the race result of canoe sprint could not be ignored during the past decades. Along with the development and application of valid and reliable technology, diagnostics in canoe sprint became more extensive. Historically, the first cycling ergometer was invented in Paris in 1896; the Douglas gas analysis technique was invented as early as 1911; and the first portable spirometriy was invented by two German scientists at the beginning of the 1940 s (HOLLMANN ET AL., 2006). However, it was not until Pyke et al. (1973) that the first ergometer modified from the Monark cycling ergometer was applied to kayaking. The first application of Douglas gas analysis technique on open water kayaking was reported in 1976 (TESCH ET AL., 1976). The modern air-brake kayak ergometer was invented in 1988 (LARSSON ET AL., 1988). Additionally, the portable spirometry was first applied to open water kayaking in 1992 (GRAY, 1992) (Figure 2-5). The development of technique promoted changes in the use of diagnostics in canoe sprint from a result-emphasis to a process-emphasis.

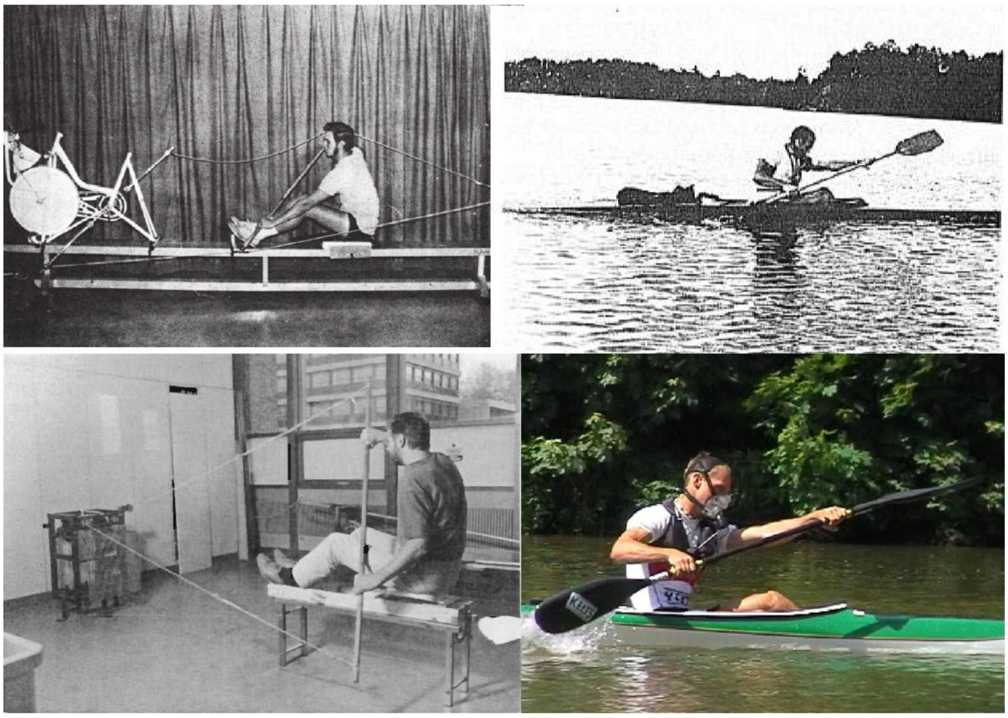

Figure 2-5: Ergometer and portable spirometry in kayaking (top left is the first kayak ergometer modified from Monark cycling ergometer (PYKE ET AL., 1973); bottom left is the first modern air-brake kayak ergometer (LARSSON ET AL., 1988); top right is the first application of Douglas gas analysis technique on open water kayaking (TESCH ET AL., 1976); bottom right is the application of portable spirometry on open water kayaking (REGNER, 2004))

The other aspect of diagnostics in canoe sprint would be biomechanics. Systematic biomechanical diagnostics date back to the former Soviet Union and East Germany in the 1970 s (SPERLICH & BACKER, 2002). After the reunification, German biomechanical experts continued their investigation on canoe sprint (LENZ, 1994). At the same time, experts from other countries, including Great Britain (BEGON ET AL., 2009), Australia (BAKER ET AL., 1999), New Zealand (JACKSON ET AL., 1992), Italy (LIMONTA ET AL., 2010), Portugal (GOMES ET AL., 2011), and China (马祖长, 2007), started to focus on biomechanical diagnostics in canoe sprint from aspects of paddle force on water and on ergometer, as well as paddling kinetics. All of these investigations expanded the knowledge of canoe sprint. In summary, physiological and biomechanical diagnostics might also be one of the causes of the development of race results in canoe sprint during the past decades.

2.1.7 Summary

The development of race results in canoe sprint during the past decades resulted from the contributions of various aspects. The recruitment of taller and stronger athletes improved the physiological capacity of paddlers. Direct investigation on energy contribution in canoe sprint enhanced the emphasis on aerobic capacity and aerobic endurance training. Advancement of equipment design improved the efficiency of paddling. Physiological and biomechanical diagnostics in canoe sprint led to a more scientific way of training. Additionally, other aspects might also have contributed to the development of race results during the past decades. For example, the establishment of national teams after World War II provided the possibility of systematic training, and the use of drugs in last century accelerated the development of race results in that period.

2.2 Overestimate of Relative Aerobic Contribution with Maximal Accumulated Oxygen Deficit (MAOD)

2.2.1 Introduction

The findings of W_{AER} % with maximal physical effort in various durations from Astrand and Rodahl (1970) have been widely used. Their findings have played an important part in many physiology textbooks (ASTRAND ET AL., 2003; BADTKE, 1995; BOMPA & HAFF, 2009; GRASSI ET AL., 2009; HOLLMANN & STRUEDER, 2009; POWERS & HOWLEY, 2007; WEINECK, 1986; WILMORE ET AL., 2008) and official material of sport federations (KAHL, 2005; THOMPSON, 2009) since the 1970 s. However, their findings tended to underestimate the W_{AER} % as shown by recent investigators (GASTIN, 2001). Most of them used the method of MAOD introduced by Medbo et al. (1988) to calculate the energy supply.

Whereas, the introduction of MAOD brought the knowledge of W_{AER} % in sports closer to the real physiological character, the debate over the method of MAOD existed along with the popularization of MAOD (BANGSBO, 1992). Some case studies found that MAOD could result in an underestimate of anaerobic energy production (BANGSBO, 1998; DUFFIELD ET AL., 2004, 2005a), because of its principals to determine the accumulated oxygen deficit (OD) (BANGSBO, 1998; BANGSBO ET AL., 1990; BANGSBO ET AL., 1993). Given that there was a lack of cross-sectional comparisons among different methods of calculating energy supply, it was hoped that the answer of whether an underestimate or overestimate of anaerobic energy production could be found by summarizing various studies that reported W_{AER} % with different methods of calculating energy supply.

Therefore, the purpose of this study was to review the relevant studies that reported the W_{AER} % in various maximal exercises. The studies utilizing MAOD were compared to studies that utilized other methods. Because there was no disagreement on calculating the aerobic part of energy supply, this review emphasized primarily the calculating of anaerobic energy supply.

2.2.2 Historical Overview of Calculating Energy Supply

The development of calculating energy supply in humans originated from one point, but it can be divided into two directions. The first direction is related to OD and it emphasizes aerobic and anaerobic energy supply. The second direction is based on the three pathways of energy supply (anaerobic alactic, anaerobic lactic, and aerobic). The methods of calculating energy supply in these two directions are named MAOD and phosphocreatine-lactate-oxygen (Pcr-La-O_2) in this review, respectively.

The concept of OD was first introduced by Krogh and Lindhard (1920), and it had been used as a means to determine anaerobic energy production during both sub- and maximal exercises. The description of W_{AER} % provided by Astrand and Rodahl (1970) was also based on OD as reported in 1960 (ASTRAND ET AL., 1960), whereas the OD was calculated as the difference between accumulated actual oxygen uptake (VO_2) and the oxygen demand, which is determined by dividing the work done on a bicycle ergometer by an assumed mechanical efficiency (23 %). During the 1980 s, the basic ideas of the MAOD principle were investigated independently by three groups (FOSTER ET AL., 1989; HERMANSEN & MEDBO, 1984; MEDBO ET AL., 1988; PATE ET AL., 1983), and the method was popularized after it was introduced by Medbo et al. (1988). Different from the previous OD methods, the oxygen demand during maximal exercise in MAOD is calculated by extrapolating the linear relationship between exercise intensity and VO_2 in submaximal incremental exercise. Therefore, the aerobic and anaerobic energy release can be expressed in the form of VO_2. With a caloric equivalent of 21.131 $J \cdot ml^{-1}$ (STEGMANN, 1977), the energy release from these two pathways can be expressed in joule or calorie. Currently, MAOD is the most popular method utilized to calculate energy supply in high-intensity exercise.

The method of Pcr-La-O_2 started from the knowledge of oxygen debt. Krogh and Lindhard reported the phenomenon of excess oxygen consumption at the transition from work to rest in 1920 (KROGH & LINDHARD, 1920). Hill et al. attached the term *oxygen debt* to this phenomenon and hypothesized that the oxygen debt was due to the delayed oxidation of a fraction of lactic acid produced during the anaerobic process of muscular activity (HILL & LUPTON, 1923). Margaria et al. demonstrated the independence of the oxygen debt to the lactic acid removal from blood, and subdivided the overall oxygen debt in alactic oxygen debt and the lactic oxygen debt (MARGARIA ET AL., 1933b). Later on, Margaria et al. demonstrated an oxygen-lactate equivalent of 3.3 ml $O_2 \cdot kg^{-1} \cdot mM^{-1}$ in 1963 (MARGARIA ET AL., 1963), which was also reported by di Prampero et al. as 3.0 ml $O_2 \cdot kg^{-1} \cdot mM^{-1}$ (DI PRAMPERO, 1981); given that, the energy production from the lactic part of oxygen debt, or glycolysis, could be equal to VO_2. Meanwhile, the alactic part of oxygen debt was investigated by Knuttgen (1970), as well as by Robert and Morton (1978), which led to the possibility of calculating the energy supply from the alactic anaerobic pathway in an equivalent of VO_2. The anaerobic alactic energy was also calculated in some studies from the volume of phospocreatine in a certain muscle mass (CAPELLI ET AL., 1998; DI PRAMPERO, 1981). Compared to the anaerobic process including both lactic and alactic acid, the quantification of aerobic process was of less debate. During maximal muscular effort, the metabolic respiratory quotient was $>$ 1.0. Nearly all of the aerobic energy was provided from the depletion of carbohydrate in the presence of oxygen, and the caloric equivalent of 1 ml oxygen was 21.131 J (STEGMANN, 1977). Therefore, all three energy types that release from alactic anaerobic, lactic anaerobic, and aerobic pathways could be calculated with a unit of joule or calorie. In recent years, the method of Pcr-La-O_2 has become more popular (BENEKE ET AL., 2004; BUGLIONE ET AL., 2011; BUSSWEILER & HARTMANN, 2012).

2.2.3 Descriptions of Methods in Calculating Energy

As provided by Medbo et al. (2010;1988), the idea of using the accumulated OD as a measure of the anaerobic energy release during maximal exercise is based on the following four principles:

1) Energy release (ATP-resynthesis) is aerobic or anaerobic. The anaerobic part is thus the total energy release minus the aerobic part. The aerobic part is taken from the measured VO_2.

2) During exercise at moderate intensities where anaerobic processes are negligible, VO_2 increases linearly, with exercise intensity measured as the speed of running or the power of ergometer cycling at constant frequency

(Figure 2-6, left panel). Since there is no anaerobic contribution, the measured VO_2 reflects the total rate of ATP-turnover or oxygen demand. Consequently, during these conditions, the total ATP-turnover rate or oxygen demand increases linearly by exercise intensity. This linear relationship between exercise intensity and oxygen demand is extrapolated to maximal intensities, where anaerobic contribution is not negligible.

3) During exercise at constant intensity the rate of ATP-turnover is constant throughout the exercise even until exhaustion (Figure 2-6, right panel).

4) The accumulated OD is taken by integrating OD over the exercise period (see doted area in Figure 2-6).

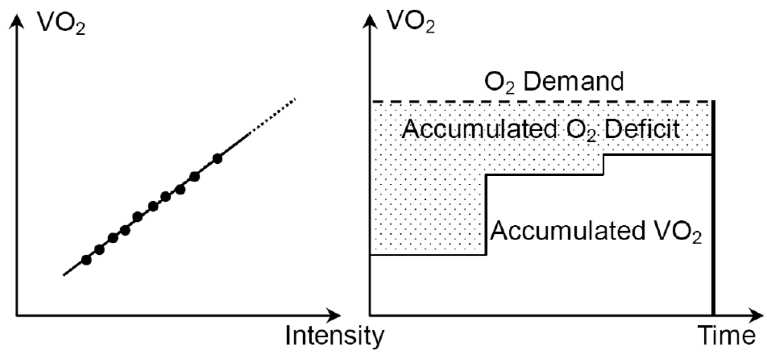

Figure 2-6: Scheme of MAOD provided by Medbo et al. (1988)

Given the four principles, it is required, in consideration of reliability, that a minimum of 8–10 steps for incremental tests, taking the VO_2 in the period 8–10 min of each step; constant intensity in the range of 35-90 %VO_{2max} for each step; and a fixed Y-intercept for the linear function are needed to determine the relationship of oxygen demand versus exercise intensity (MEDBO, 2010). However, these test requirements are very time-consuming. Thereafter, the experimental design of MAOD was modified by investigators in order to make it more practical. For example, the number of steps was deceased to 4–8 (GASTIN, P.B. & LAWSON, D.L., 1994; SEILER & KJERLAND, 2006); the duration for each step was deceased to 5 min (BILLAT, BEILLOT, ET AL., 1996; BISHOP, 2000; DUFFIELD ET AL., 2005a; GASTIN, P.B. & LAWSON, D.L., 1994); a fixed Y-intercept was not utilized (BILLAT, BEILLOT, ET AL., 1996; BISHOP, 2000; DUFFIELD ET AL., 2005a);

and the method was used in other movements (e.g., kayaking (BISHOP, 2000), swimming (BILLAT ET AL., 1996), and rowing (DE CAMPOS MELLO ET AL., 2009)).

Even though no consistent method of Pcr-La-O_2 exists, there are several foundations of this method:

1) The energy release from the anaerobic alactic pathway is calculated either from the fast component of oxygen debt (BENEKE ET AL., 2004; KNUTTGEN, 1970; ROBERTS & MORTON, 1978), from the volume of phospocreatine in a certain muscle mass (CAPELLI ET AL., 1998; DI PRAMPERO, 1981), or from the OD before the appearance of the steady state of VO_2 (HARTMANN ET AL., 1988b).

2) The energy release from the anaerobic lactic pathway is calculated from the net production of blood lactate above the rest level during exercise (DI PRAMPERO, 1981; MARGARIA ET AL., 1933b).

3) The energy release from the aerobic pathway is calculated from the accumulated VO_2 above the rest level during exercise (STEGMANN, 1977).

Anaerobic alactic, anaerobic lactic, and aerobic energy supply are termed as W_{PCR}, W_{BLC}, and W_{AER}, respectively, with W_{TOT} for the total energy supply. Calculation of each energy supply could be performed by the following equations：

$\mathbf{W_{PCR}}$ = VO_{2PCR} (ml) × caloric equivalent (J·ml^{-1})

$\mathbf{W_{BLC}}$ = net blood lactate (mmol·l^{-1}) × oxygen-lactate equivalent (ml·kg^{-1}·mmol^{-1}·l) × body mass (kg) × caloric equivalent (J·ml^{-1})

$\mathbf{W_{AER}}$ = VO_2（ml）× caloric equivalent（J·ml^{-1}）

$\mathbf{W_{TOT}}$ = W_{PCR} + W_{BLC} + W_{AER}

Among them, VO_{2PCR} is the fast component of oxygen debt (KNUTTGEN, 1970; MARGARIA ET AL., 1933a; ROBERTS & MORTON, 1978)；caloric equivalent is 21.131 J·ml^{-1}, corresponding to a respiratory exchange ratio > 1.0 (STEGMANN, 1977)； net blood lactate is the peak value during recovery minus the rest value; oxygen-lactate equivalent is 3.0 ml·kg^{-1}·mmol^{-1}·l, under the consumption of a distribution space of lactate of approximately 45 % of the body mass (DI PRAMPERO, 1981); VO_2 is the actual VO_2 during maximal exercise above the rest level.

2.2.4 Analysis of Relevant Reports of W_{AER} %

Studies up to the year of 2012 (raw data see Appendix 2) on energetics or energy contribution in sport were searched in PubMed, and 47 investigations (153 data of W_{AER} %, together with 14 data of our own) were selected, which were then divided into two groups according to the methods of calculating energy supply, as mentioned previously. Among the selected investigations, 32 (100 data of W_{AER} %) utilized the MAOD method, whereas 15 (69 data of W_{AER} %) utilized the Pcr-La-O_2 method. MAOD was the most popular method utilized during the past few decades.

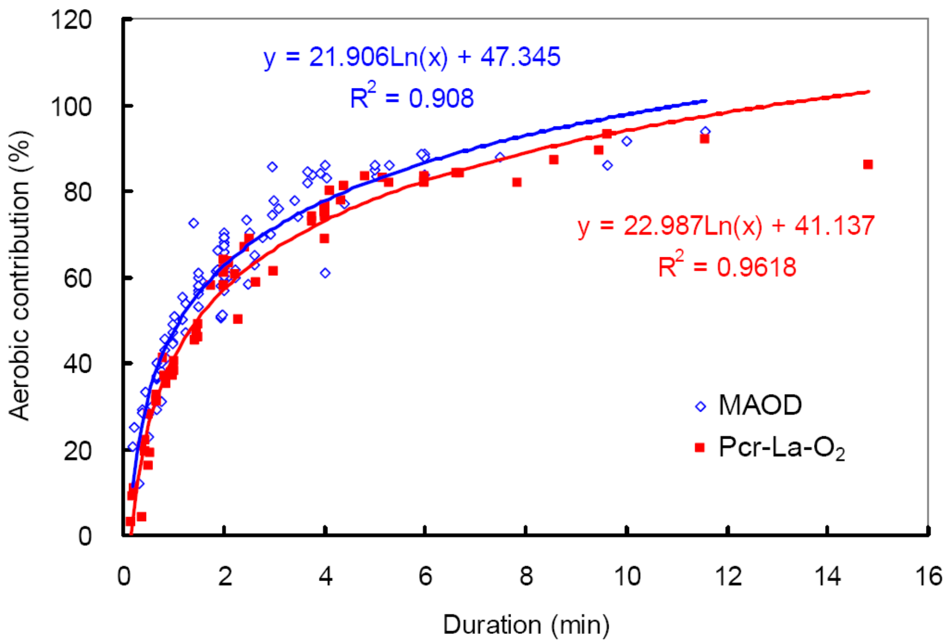

Figure 2-7: Correlation between W_{AER} % and duration of maximal exercise based on summary analysis of the literature (raw data see Appendix 5)

All of the reports of W_{AER} % during maximal exercise were summarized into two groups according to the methods utilized (MAOD vs. Pcr-La-O_2). Two exponential regressions were performed to the two groups of data. It was found that the W_{AER} % from MAOD was higher than those from Pcr-La-O_2 (Figure 2-7). The results suggested an overestimate of W_{AER} % with MAOD compared to with Pcr-La-O_2.

According to two regression functions in Figure 2-7, the W_{AER} % in maximal exercise with various durations was presented in Figure 2-8. Although the W_{AER} % was higher for certain durations of maximal exercise with MAOD than it was with Pcr-La-O_2, it still could not be proven which method was more accurate. Therefore, an exponential regression function for all the data using one of the two methods was developed (Figure 2-8, Total). The equation of

$$y = 22.253\text{Ln}(x) + 44.948$$

(y = W_{AER} % in percentage, x = duration of the maximal exercise in minute) could be used to predict the W_{AER} % for the maximal exercise with certain durations. For example, the average finishing time in the final race in men's single canoe 1000 m in the 2011 World Championship was 4.16 min. According to the above-mentioned equation, the W_{AER} % in this exercise could be calculated as 76.7 %. Further, the half-half point of duration for aerobic and anaerobic energy release was calculated to 75.3 s. This updated value is consistent to that (75 s) reported by Gastin (2001).

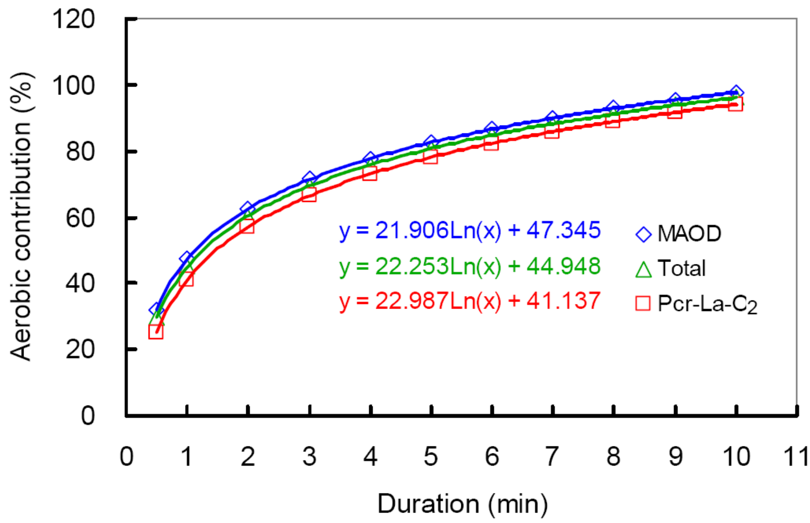

Figure 2-8: Recommendation of W_{AER} % in maximal exercises with different durations according to the equations calculated from the data using MAOD and Pcr-La-O_2, as well as from all of the data (Total), raw data see Appendix 6

2.2.5 Limitations of MAOD

Since the introduction by Mebdo et al. in 1988, the reliability of using MAOD to calculate energy supply during maximal exercise has been questioned (BANGSBO, 1992, 1998; BANGSBO ET AL., 1990). Briefly, three of the principles of MAOD are challenged by the findings from other investigators.

1) Does VO_2 increase linearly with exercise intensity even at higher intensity?

The linear relationship between VO_2 and exercise intensity at moderate intensity (35-90 $\%VO_{2max}$ (MEDBO, 2010)) is the primary assumption of MAOD. With this linear regression equation, the oxygen demand at higher (> 90 $\%VO_2$max) intensity is extrapolated. However, it was found that the relationship between exercise intensity and VO_2, especially at higher intensity, was exponential (Figure 2-9, actual curve) rather than linear (Figure 2-9, linear curve 1)) in running (MENIER & PUGH, 1968), cycling (PUGH, 1974), rowing (NOZAKI ET AL., 1993; SECHER, 1992), and canoeing (see Chapter 5). According to the protocol of MAOD, the oxygen demand at maximal exercise includes the accumulated VO_2, the area of ① and ②, when extrapolating the linear curve 1.

However, the oxygen demand would cover an additional area of ③ when extrapolating the actual curve, as illustrated in Figure 2-9. Therefore, there is a small underestimate of the anaerobic energy share with MAOD, which results in an overestimate of W_{AER} %. The underlying reason for a higher VO_2 at high intensity could be explained by the observation of decrease in mechanical efficiency at higher intensities (GAESSER & BROOKS, 1975; GLADDEN & WELCH, 1978; LUHTANEN ET AL., 1987).

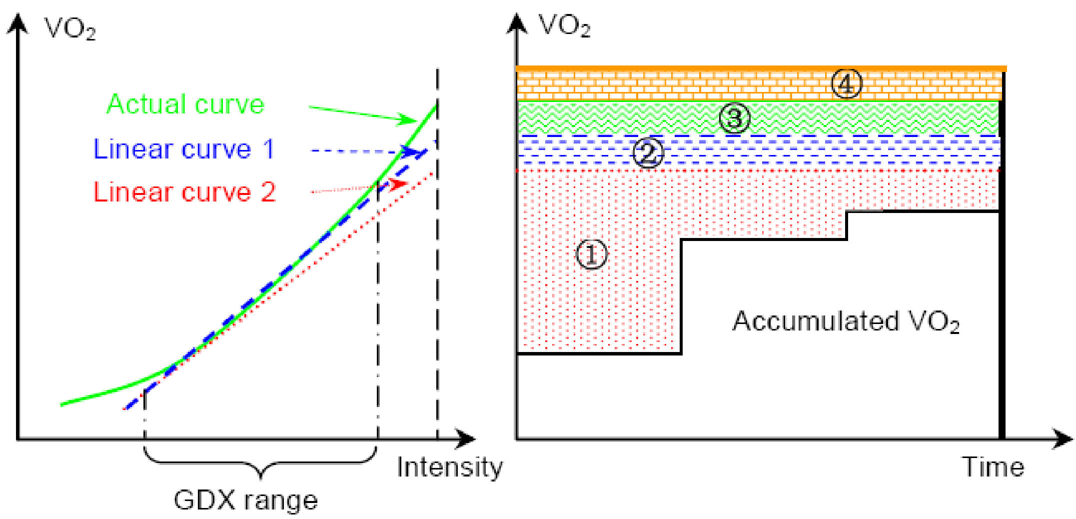

Figure 2-9: Illustration of the causes of overestimate in W_{AER} % with MAOD (GDX: graded exercise)

2) What is the influence of shortening the duration of each step in an incremental test?

After being introduced by Medbo et al. in 1988, the method of MAOD was widely used. However, some modifications were made by investigators during the application. One of which was shortening the duration of each step in incremental tests from 8–10 min to 5–8 min (BILLAT ET AL., 1996; BISHOP, 2000; DUFFIELD ET AL., 2005a; GASTIN & LAWSON, 1994). However, it was demonstrated that this would lead to a lower slope of the linear regression (Figure 2-9, linear curve 2), and therefore a lower accumulated OD if the accumulated VO_2 is the same. This means when the duration of each step in incremental test shortens from 8–10 min to 5–8 min, an additional underestimate of anaerobic energy release (Figure 2-9, area ②) could happen, leading to an additional overestimate of W_{AER} %.

3) Is anaerobic part of energy release in submaximal exercise negligible?

Another principle of MAOD is that the anaerobic process during exercise at moderate intensities is negligible. However, it was found that the blood lactate can reach approximately 4 mM when the intensity was 70–80 %VO_{2max} (ALIVERTI ET AL., 2009; BENEKE, 2003a; BILLAT ET AL., 2003), which means at the upper range of the submaximal exercise, as suggested by Medbo (35–90 %VO_{2max}) (2010), the blood lactate can increase to a certain high level, and this part of anaerobic energy release cannot be neglected. Consequently, the neglect of the anaerobic processes during exercise at moderate intensities can cause another underestimate of anaerobic energy (Figure 2-9, ④), and again, an overestimate of W_{AER} %.

4) The shorter the duration of maximal exercise is, the greater overestimate of W_{AER}% with MAOD will be

Given the above-mentioned points, it seems apparent in Figure 2-9 that the area of ③ and ④ will be larger if the extrapolation is performed further, right away from 90 %VO_{2max}. It is already known that the time to exhaustion decreases with the increase of exercise intensity (HECK, 1990a). Therefore, the overestimate of W_{AER} % with MAOD will be greater when the duration of maximal exercise is shorter, resulting from the decrease of mechanical efficiency and the increase of energy release from anaerobic system. This speculation has been proved by the findings from kayakers (see Chapter 3), where the overestimate of W_{AER} % at 40 s (36.0 % vs. 30.0 %, $p < 0.05$) was much greater than at 120 s (60.9 % vs. 57.5 %, $p > 0.05$).

2.2.6 Summary

MAOD is the most popular method in calculating the energy contribution in high-intensity exercise. Utilizing MAOD could lead to an overestimate of W_{AER} % compared to the method of Pcr-La-O_2. The overestimate of W_{AER} % could result from the linear extrapolation of VO_2 at high intensity, the neglect of anaerobic energy release in submaximal incremental test, and the shortening of the duration of each step in the submaximal incremental test. However, because no study has compared the content validity between MAOD and Pcr-La-O_2, it is still not clear which method can generate more accurate results and which method is more reliable. The muscle biopsy technique might provide better insight into anaerobic energy production during intensive exercise (GASTIN, 2001).

3 Possible Factors Associated with Relative Aerobic Energy Contribution in Kayaking

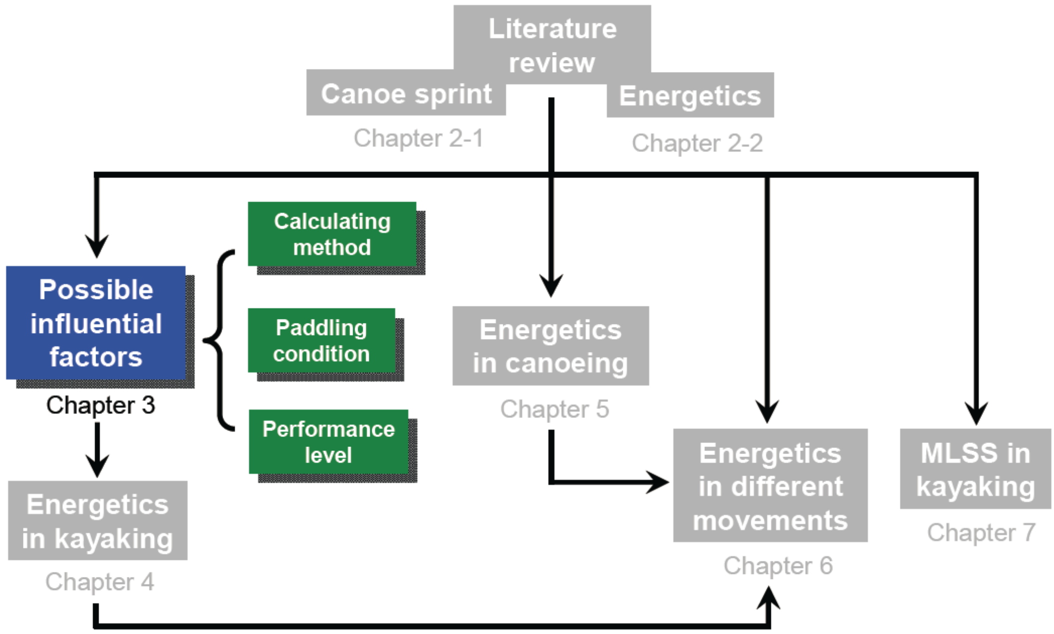

Illustration of the research design - Chapter 3

3.1 Introduction

Since the first study in 1997 (BYRNES & KEARNEY, 1997), the W_{AER} % in kayaking has been widely investigated (BISHOP, 2000; BISHOP ET AL., 2001, 2002; BISHOP ET AL., 2003; BUGLIONE ET AL., 2011; NAKAGAKI ET AL., 2008; ZAMPARO ET AL., 1999). However, a range of variation in W_{AER} % in kayaking was observed. For example, the W_{AER} % varied from 29 % to 40 % (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008) and from 57 % to 69 % (BISHOP, 2000; BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008; ZAMPARO ET AL., 1999) in 40 s and 120 s maximal padding.

Many factors might contribute to the variation of W_{AER} % in kayaking. The methods utilized to calculate the energy contributions, different paddling conditions (on ergometer vs. on water), and the level of performance are three potential factors. MAOD was commonly used to calculate the energy contribution in kayaking, but this method was suspected to overestimate W_{AER} % during high-intensity exercises (BANGSBO, 1998; DUFFIELD ET AL., 2004, 2005a) (also see Chapter 2). The kayak ergometer is able to simulate the physiological demands of short-term, high-intensity kayaking (VAN SOMEREN ET AL., 2000). However, it was unknown whether the kayak ergometer would alter the W_{AER} % in kayaking. Adults kayakers were heavier and taller (RYNKIEWICZ & RYNKIEWICZ, 2010), and they had a greater training volume than junior kayakers (i.e., 874 h in year for ≥ 21-year group vs. 690 h in year for 16-year group) (KAHL, 2005). However, the W_{AER} % between adult and junior kayakers was still unclear.

Therefore, the objective of this study was to investigate the influence of energy calculation method, paddling condition, and performance level on W_{AER} % in kayaking. It was hypothesized that the calculation method and performance level would affect W_{AER} % in kayaking. The findings of this study can provide information in comparing the W_{AER} % in kayaking findings among different studies.

3.2 Methods

3.2.1 Study 1 - Energy Calculation Method

3.2.1.1 Subjects

Eleven junior female kayakers of regional level (JF) participated in study 1. Subjects performed maximal paddling twice (40 s and 2 min) and step-test paddling once on an ergometer on separate days (Figure 3-1). Anthropometric data of these kayakers were provided in Table 3-1. All of the participants in this study, as well as in study 2 and study 3, read and signed a consent form before measurement. These studies were conducted according to the corresponding ethical standards.

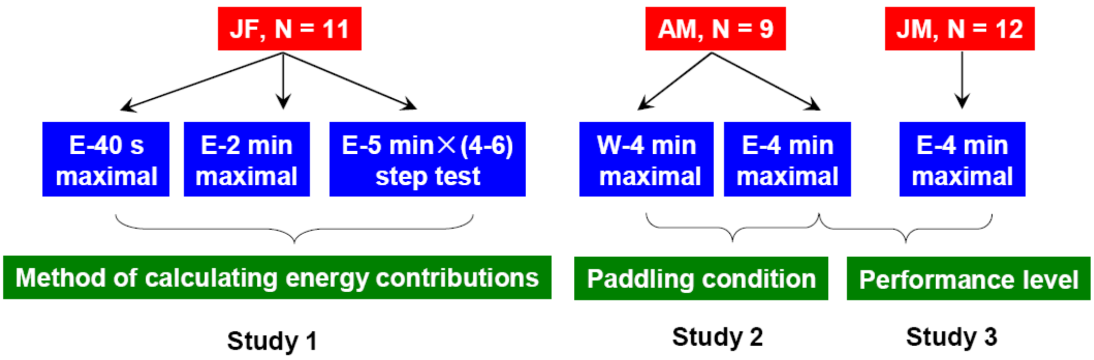

Figure 3-1: Description of the study design (J = junior; A = adult; F = female; M = male; W = on water; E = on ergometer)

3.2.1.2 Maximal and Step-Test Paddling

The durations in maximal padding were designed to simulate the corresponding racing distances (40 s for 200 m and 2 min for 500 m). The tests were performed on an air-braked kayak ergometer (Dansprint, I Bergmann A/S, Hvidovre, Denmark). No intensive exercise was allowed the day before the test, and no food was allowed two hours before the test; water was permitted. A typical diet with high carbohydrate was adhered to by the subjects before the tests. Subjects performed a 10 min warm-up with self-controlled intensity and had a 5 min rest prior to the maximal paddling test. The subjects were instructed to paddle with a self-chosen strategy. Oral encouragement was given during the paddling to increase subjects' motivation. A portable breath–by-breath gas analyzer (MetaMax 3B, Cortex Biophysic, Leipzig, Germany) was used to measure the VO_2, expired carbon dioxide (VCO_2), and minute ventilation (VE) from warm-up to 10 min after the end of maximal paddling. From the earlobe of each subject, 20 µL blood was taken prior to warm-up, immediately after the warm-up, and before the maximal paddling, as well as at the 1st, 3rd, 5th, 7th, and 10th min time points during the recovery. The spirometric information was measured, saved, and analyzed with the standard software (MetaSoft, Cortex Biophysic, Leipzig, Germany). The blood samples were analyzed with a lactate analyzer (Biosen S_line, EKF Diagnostic, Barleben, Germany). Individual fan resistance (3 for juniors in study 1 and study 3; 5 for adults in study 2) and distance between seat and foot stretcher on the ergometer were individually adjusted prior to paddling.

Table 3-1: Anthropometric and physical data of all the kayakers

	Height	Mass	Age	VO_{2peak}*		Training Experience
	[cm]	[kg]	[yrs]	[l/min]	[ml/min/kg]	[yrs]
JF (N = 11)	172 ± 4	65.4 ± 4.2	14 ± 1	2.767 ± 0.318	42.6 ± 4.9	1.5 ± 0.3
AM (N = 9)	189 ± 3§	84.2 ± 6.0§	21 ± 3§	4.749 ± 0.538§	56.3 ± 4.1§	5.3 ± 2.0§
JM (N = 12)	184 ± 6	73.7 ± 6.6	16 ± 1	4.013 ± 0.413	54.7 ± 6.3	1.1 ± 0.4

J = junior, A = adult, F = female, M = male, * average values of last 30 s during 4 min or 2 min maximal paddling, § significant from JM ($p < 0.05$)

The step test started from an intensity of 40–50 watts, with an increment of 15 watts, and it stopped when the paddlers could not keep paddling with the required intensity. The duration of each step was 5 min, with 1 min brake between each two steps for blood taking. Steps 4–6 were performed by the paddlers.

3.2.1.3 Calculating the Energy Contribution

MAOD became popular after it was introduced in 1988 (MEDBO ET AL., 1988), and it was modified by other researchers (see Chapter 2) (BISHOP, 2004; BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008). The modified MAOD, instead of the original MAOD, was used in this study. The power and

VO_2 in the last two minutes of each step was averaged and used for this step. Accordingly, an individual linear regression function between intensity (power in watt) and VO_2 (ml/min) was drawn for each subject. By extrapolating this function for the power during 40 s and 120 s maximal paddling, an oxygen demand could be calculated for each power. Total energy contribution (W_{TOT}) could be calculated from the oxygen demand, with a caloric equivalent of 21.131 $J \cdot ml^{-1}$ (DI PRAMPERO, 1981). The difference between oxygen demand and actual VO_2 was calculated as OD, which could then be calculated into anaerobic energy contribution (W_{ANA}). Further, the aerobic energy contribution (W_{AER}) was calculated directly from the actual accumulated VO_2. Additionally, W_{AER} % could be calculated as W_{AER} % = 100 × (W_{AER} / (W_{AER} + W_{ANA})).

The method of Pcr-La-O_2 (as named in Chapter 2), is based on the theory that energy was produced in three pathways (anaerobic alactic, anaerobic lactic, and aerobic). The methodology introduced by Wilkie (1980) was one of the popularly utilized ones. However, this study utilized the methodology implemented by Beneke et al. (2004; 2002), in which the anaerobic alactic energy (W_{PCR}) was calculated from the fast component of oxygen debt after maximal exertions (KNUTTGEN, 1970; MARGARIA ET AL., 1933a; ROBERTS & MORTON, 1978). The anaerobic lactic energy (W_{BLC}) was calculated from net blood lactate in maximal paddling, with an oxygen-lactate equivalent of 3.0 $ml \cdot kg^{-1} \cdot mmol^{-1} \cdot l$ (DI PRAMPERO, 1981). The aerobic energy was calculated from the actual accumulated VO_2 (W_{AER}) above rest level, which was fixed at 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$ for males and 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for females (CIBA-GEIGY, 1985). With a caloric equivalent of 21.131 $J \cdot ml^{-1}$ (DI PRAMPERO, 1981), these three parts of energy contribution could be calculated into kilojoule. Therefore,

$W_{TOT} = W_{PCR} + W_{BLC} + W_{AER}$,

$W_{ANA} = W_{PCR} + W_{BLC}$,

W_{AER} % = 100 × (W_{AER} / W_{TOT}).

3.2.1.4 Statistical Analysis

The energy contributions were calculated using MAOD and Pcr-La-O_2 for the same individual. The absolute W_{ANA}, absolute W_{AER}, absolute W_{TOT}, and

W_{AER} % between the two methods were compared using two-tail paired t-tests. A type-I error rate was set at 0.05.

3.2.2 Study 2 - Paddling Condition

3.2.2.1 Subjects

Nine adult male national level (AM) kayakers participated in two maximal paddling sessions (4 min on ergometer, 4 min on water) on separate days (Figure 3-1). Anthropometric data of these kayakers are provided in Table 3-1.

3.2.2.2 Maximal Paddling

The duration of 4 min was chosen to simulate the 1000 m racing in this study. Subjects performed one maximal paddling session on a kayak ergometer (Dansprint, I Bergmann A/S, Hvidovre, Denmark) and maximal paddling on water with racing boats. The test procedure was the same as the maximal paddling in study 1.

3.2.2.3 Calculating the Energy Contribution

The method of Pcr-La-O_2, as described in study 1, was utilized in this study.

3.2.2.4 Statistical Analysis

The energy contributions on a kayak ergometer and on water were calculated for the same individual. The absolute W_{PCR}, absolute W_{BLC}, absolute $W_{ANA,}$ absolute $W_{AER,}$ absolute W_{TOT}, and W_{AER} % between the two paddling conditions were compared using two-tail paired t-tests. A type-I error rate was set at 0.05.

3.2.3 Study 3 - Performance Level of Paddler

3.2.3.1 Subjects

Nine adult male national level (AM) kayakers (see study 2) and twelve junior male regional level (JM) kayakers participated in 4 min maximal paddling on an ergometer to simulate the 1000 m racing (Figure 3-1). Anthropometric data of these kayakers are provided in Table 3-1.

Table 3-2: Energy contributions in maximal paddling

Study			W_{PCR} [kJ]	W_{BLC} [kJ]	W_{ANA} [kJ]	W_{AER} [kJ]	W_{TOT} [kJ]
1	JF-40 s (N = 11)	MAOD	/	/	41.9 ± 8.8*	23.3 ± 3.5	65.2 ± 11.5*
		Pcr-La-O_2	32.0 ± 5.5	20.7 ± 4.5	52.8 ± 4.0	23.3 ± 3.5	76.1 ± 5.5
	JF-2 min (N = 11)	MAOD	/	/	64.1 ± 27.9	92.4 ± 12.2	156.5 ± 28.3
		Pcr-La-O_2	32.9 ± 6.3	35.3 ± 5.3	68.2 ± 10.0	92.4 ± 12.2	160.6 ± 17.3
2	AM-4 min (N = 9)	W	60.4 ± 14.6	49.4 ± 8.1	109.8 ± 16.0	332.2 ± 37.0	442.0 ± 36.0
		E	56.2 ± 11.3	44.3 ± 13.3	100.4 ± 20.8	325.8 ± 37.2	426.2 ± 46.6
3	AM-4 min (N = 9)	E	56.2 ± 11.3	44.3 ± 13.3	100.4 ± 20.8	325.8 ± 37.2	426.2 ± 46.6
	JM-4 min (N = 12)	E	46.0 ± 13.0	40.2 ± 7.8	86.2 ± 17.8	275.4 ± 34.9§	361.6 ± 42.6§

J = junior; A = adult; F = female; M = male; W = on water; E = on ergometer; MAOD = maximal accumulated oxygen deficit; Pcr-La-O_2 = method based on three energy pathways; W_{PCR} = anaerobic alactic energy contribution; W_{BLC} = anaerobic lactic energy contribution; W_{ANA} = anaerobic energy contribution; W_{AER} = aerobic energy contribution; W_{TOT} = total energy contribution; * = significant from Pcr-La-O_2 in JF-40 s ($p < 0.05$); § = significant from AM-4 min on ergometer

3.2.3.2 Maximal Paddling

Subjects performed one maximal paddling session on a kayak ergometer (Dansprint, I Bergmann A/S, Hvidovre, Denmark). The test procedure was the same as the maximal paddling in study 1.

3.2.3.3 Calculating the Energy Contributions

The method of Pcr-La-O_2, as described in study 1, was utilized in this study.

3.2.3.4 Statistical Analysis

The energy contributions were calculated for two groups of subject. The absolute W_{PCR}, absolute W_{BLC}, absolute W_{ANA}, absolute W_{AER}, absolute W_{TOT}, and W_{AER} % between the two groups were compared using two-tail non-paired t-tests. A type-I error rate was set at 0.05.

3.3 Results

3.3.1 Study 1 - Energy Calculation Method

MAOD resulted in smaller absolute W_{ANA} and absolute W_{TOT}, but greater W_{AER} % compared to the results of Pcr-La-O_2 ($p < 0.05$) in 40 s paddling (Table 3-2, Figure 3-2). No significant difference was observed between the two methods in 2 min paddling.

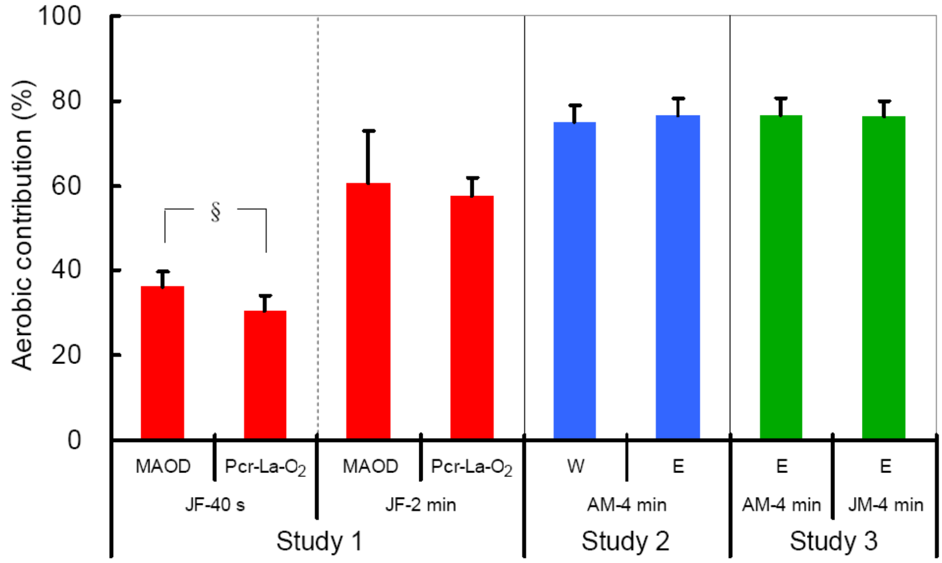

Figure 3-2: W_{AER} % in maximal paddling (J = junior; F = female; A = adult; M = male; W = on water; E = on ergometer; § significant between MAOD; and Pcr-La-O_2 ($p < 0.05$)), raw data see Appendix 7

3.3.2 Study 2 - Paddling Condition

No significant difference was observed between the paddling conditions ($p > 0.05$) (Table 3-2, Figure 3-2).

3.3.3 Study 3 - Performance Level of Paddler

Adult kayakers had greater absolute W_{AER} and absolute W_{TOT} than junior kayakers had ($p < 0.05$) (Table 3-2). No significant difference was observed in other comparisons ($p > 0.05$).

3.4 Discussion

Because a wide range of W_{AER} % in kayaking was reported during the past years, the aim of the current study was to investigate three possible factors associated with W_{AER} % in kayaking. We found that the energy calculation method might be an influencing factor on W_{AER} % in short-duration kayaking. Adult kayakers had greater absolute W_{AER} and absolute W_{TOT} than junior kayakers had. W_{AER} % in maximal kayaking seemed to be independent of paddling condition and level of performance.

The underestimate of W_{ANA}, which results in the overestimate of W_{AER} %, with MAOD has been documented since its introduction (BANGSBO, 1992, 1998; DUFFIELD ET AL., 2004). First, it was reported that the relationship between intensity and VO_2 was exponential instead of linear (MENIER & PUGH, 1968; NOZAKI ET AL., 1993; PUGH, 1974; SECHER, 1992). At higher intensity, there would be a decrease of efficiency (GAESSER & BROOKS, 1975; GLADDEN & WELCH, 1978; LUHTANEN ET AL., 1987), which could lead to a higher VO_2 than that extrapolated from the linear equation. Therefore, a lower oxygen demand resulted in a lower OD and an underestimate of W_{ANA}, especially in shorter duration with higher intensity. Second, a basis of MAOD was that the anaerobic processes (alactic and lactic) were negligible at moderate intensity (MEDBO, 2010). However, the findings in this study demonstrated a lactate level of 7.3 ± 1.7 mM after the last step in incremental paddling, which was an approximation of the level of 40 s maximal paddling (7.8 ± 1.5 mM). The results suggested that the actual W_{TOT}, if in form of oxygen demand, should be higher than the actual VO_2 during incremental paddling. In other words, the actual slope of the VO_2-intensity linear equation could be steeper than that from the methodology of MAOD and could lead to an underestimate of oxygen demand and an underestimate of W_{ANA} for maximal exertions. Third, it has been reported that the modification of the incremental test by shortening the number of steps (from 8–10 steps to 4–6 steps) and the duration of each step (from 8–10 min to 5 min) could lead to a flatter slope of the VO_2-intensity linear equation with MAOD (BANGSBO, 1998; BUCK & MCNAUGHTON, 1999), which could also lead to an underestimate of oxygen demand, and then an underestimate of W_{ANA}, for maximal exertions. Comparatively, the method of Pcr-La-O_2 utilized in this study was implemented by Beneke et al. (2004; 2002), and it has been utilized in karate (BENEKE ET AL., 2004; BUSSWEILER & HARTMANN, 2012), boxing (DAVIS ET AL., 2013), and other sports (BERTUZZI ET AL., 2007). This study was the first time the method was used in kayaking, but the

W_{AER} % in this study was similar to other reports with other methods of Pcr-La-O_2 (BUGLIONE ET AL., 2011). Above all, the method of calculating energy contributions might be an influencing factor on W_{AER} % in maximal kayaking, especially in shorter durations.

The kayak ergometer has been demonstrated to accurately simulate the physiological demands of short-term, high-intensity kayaking (VAN SOMEREN ET AL., 2000). The physiological similarity between on ergometer and on water kayaking was also expanded in this study, where energy contributions were similar ($p > 0.05$, Table 3-2 and Figure 3-2). Investigations on energy contributions in kayaking were performed either on an ergometer (BISHOP, 2000; BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008) or on open water (BUGLIONE ET AL., 2011; ZAMPARO ET AL., 1999). With the findings from this study, the performing condition could be excluded from the possible influencing factors associated with W_{AER} %.

In terms of performance level, the adult kayakers produced higher levels of absolute energy, especially W_{AER} and W_{TOT} than junior kayakers did (Table 4-2), which could be attributed to their anthropometric and training experience advantages as indicated in Table 3-1. However, W_{AER} % was similar in these two groups of kayakers. Therefore, performance level could also be excluded from the possible influencing factors associated with W_{AER} %.

In summary, the methods utilized to calculate the energy contributions seemed to be the sole factor among the three studied possible factors associated with W_{AER} %. However, it could still not explain the variation in 40 s and 120 s maximal kayaking (29-40 % (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008) and 57-69 % (BISHOP, 2000; BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008; ZAMPARO ET AL., 1999)), because variation existed between relevant investigations with MAOD (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008). It seemed that some other unstudied factors (e.g., motivation and muscle fiber type in upper-body muscles) might be associated with W_{AER} %, which will need to be investigated in the future.

3.5 Conclusion

In conclusion, the method utilized to calculate the energy contributions rather than paddling condition and performance level of paddlers might be the possible factor associated with W_{AER} % in kayaking. Some other possible factors associated with W_{AER} % in kayaking need to be further investigated in the future.

4 Energetic Profile of Maximal Kayaking on Ergometer

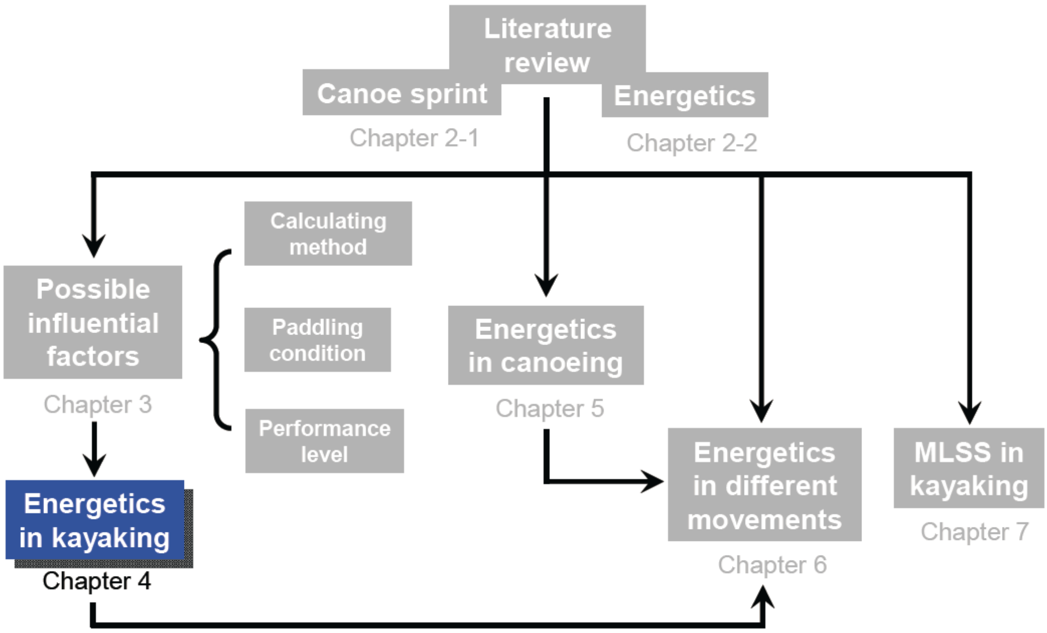

Illustration of the research design - Chapter 4

4.1 Introduction

Kayaking has been an Olympic event since its debut in 1936. Females compete in 200 m and 500 m, and males compete in 200 m and 1000 m, since the revisal by the ICF in 2009. The finishing time of the single boat in the London Olympic Games' final A were on average 45.5 s for female 200 m, 36.8 s for male 200 m, 113.2 s for female 500 m, and 210.1 s for male 1000 m (LI, 2012). The energetics for these distances vary from anaerobic dominance in 200 m to aerobic dominance in 1000 m (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008; ZAMPARO ET AL., 1999; ZOUHAL ET AL., 2012) Understanding the energetic profiles of different genders and distances in kayaking can provide information in developing training strategies.

Energetics of maximal kayaking had not received much attention until 1997 (BYRNES & KEARNEY, 1997). Byrnes and Kearney utilized a kayak ergometer and demonstrated an underestimate of W_{AER} % in kayaking found in some textbooks in the past (ASTRAND & RODAHL, 1970). However, the method used by Byrnes and Kearney (1997) as well as the method used by Nakagaki et al. (2008) and Zouhal et al. (2012) have been criticized to underestimate anaerobic energy contribution in high-intensity exercise (BANGSBO, 1992, 1998). Beneke et al. (2002) introduced another method to calculate energy production in exercise that was based on the fast component of oxygen debt and net blood lactate. This method has been used to understand the energetics in karate (BENEKE ET AL., 2004; BUSSWEILER & HARTMANN, 2012), boxing (DAVIS ET AL., 2013), and other sports (BERNARDI ET AL., 2007; BERTUZZI ET AL., 2007).

Therefore, the objective of the study is to use the method introduced by Beneke et al. to further investigate the energetic profiles in maximal kayaking. The knowledge of energetic process in maximal kayaking would be expanded with the findings in this study. In addition, the method introduced by Beneke et al. could be verified by comparing the findings from this study with those from others.

4.2 Methods

4.2.1 Subjects

From a training center, 37 healthy junior kayakers (21 females and 16 males, Table 4-1) volunteered to participate in two maximal paddling tests (40 s and 120 s for females, 40 s and 240 s for males) on different days on a kayaking ergometer (Dansprint, I Bergmann A/S, Hvidovre, Denmark). Completing the 40 s test were14 females and 15 females completed the 120 s test; 15 males completed the 40 s test and 12 males completed the 240 s test. The maximal durations were designed to mimic the Olympic racing distances. Intensive training was not allowed the day before tests. Subjects had at least 24 h between the two tests. No food, except drink, was allowed two hours before tests. A typical diet with high carbohydrate was adhered to by the subjects before the tests. Written informed consent was obtained from the parents and coaches of the subjects. The study was conducted according to the corresponding ethics requirement. The altitude, temperature, and humidity for the tests were 11 m, 19 °C, and 35 %, respectively.

Table 4-1: Anthropometric and physical characteristic of subjects

	Height	Mass	Age	VO_{2peak}*		Training experience
	[cm]	[kg]	[yrs]	[l/min]	[ml/min/kg]	[months]
40s-F (N = 14)	173 ± 4	66 ± 4	14 ± 1	2.77 ± 0.32	42.6 ± 4.9	19 ± 10
40s-M (N = 15)	184 ± 6	75 ± 7	16 ± 1	4.01 ± 0.41	54.7 ± 6.3	13 ± 9
120s-F (N = 15)	172 ± 4	65 ± 4	14 ± 1	2.77 ± 0.32	42.6 ± 4.9	19 ± 9
240s-M (N = 12)	184 ± 6	74 ± 7	16 ± 1	4.01 ± 0.41	54.7 ± 6.3	13 ± 9

* average value of last 30 s from 120 s maximal for females and 240 s maximal for males

4.2.2 Procedures

The fan resistance factor was set at 3. After setting up the ergometer, subjects performed a 10 min self-controlled warm-up and had a 5 min rest before the maximal tests. A metabolic unit (MetaMax 3B, Cortex Biophysic, Leipzig, Germany) was used to measure breath-by-breath VO_2 from the warm-up to 10 min after the end of paddling. Prior to the test of each test day, pressure, gas, and volume calibration were strictly performed according to the handbook of the equipment using a 3 l syringe and a gas of known composition (O_2: 15.00 %，CO_2: 5.00 %). Capillary blood, 20 µL, was taken from the subjects' right earlobe before the warm-up, immediately after the warm-up, before the maximal paddling, and at the 1st, 3rd, 5th, 7th, and 10th min of recovery. The blood samples were analyzed using a lactate analyzer (Biosen S_line, EKF Diagnostic, Barleben, Germany). A polar monitor (Polar Accurex Plus, Polar Electro Oy, Kempele, Finland) was utilized to measure the heart rate. Throughout the maximal trials, spoken encouragement was given by the coaches to motivate the subjects. The subjects paddled with a self-chosen strategy.

4.2.3 Calculating the Energy Contributions

Energy productions were calculated as three components, including anaerobic alactic (W_{PCR}), anaerobic lactic (W_{BLC}), as well as aerobic (W_{AER}). The total energy production (W_{TOT}) was calculated as the sum of these three components. W_{PCR} was calculated as the energy corresponding to the fast component of oxygen debt in recovery using a double exponential equation (BENEKE ET AL., 2002); W_{BLC} was calculated according to the net capillary blood lactate, which was the peak value during the recovery minus the value immediately prior to maximal paddling, with the assumption of an oxygen-lactate equivalent of 3.0 $ml \cdot kg^{-1} \cdot mmol^{-1} \cdot l$ and a 45 % of the body mass distribution of lactate (DI PRAMPERO, 1981). W_{AER} was calculated from the accumulated VO_2 during maximal paddling above a resting level, which was assumed to be 4.0 ml O_2 $kg^{-1} \cdot min^{-1}$ for males and 3.5 ml O_2 $kg^{-1} \cdot min^{-1}$ for females (CIBA-GEIGY, 1985). A caloric equivalent of $21.131 J \cdot ml^{-1}$ at respiratory exchange ratio >1.0 was utilized to convert the three components of VO_2 into kilojoule (STEGMANN, 1977). The normalized energy production of each component was calculated as each component divided by the body mass ($W_{PCR}N$, $W_{BLC}N$, $W_{AER}N$, and $W_{TOT}N$,). The relative energy production of each component (W_{PCR} %, W_{BLC} %, and W_{AER} %) was calculated as each component divided by W_{TOT}. The power of each component (E_{PCR}, E_{BLC}, and E_{AER}) was calculated as the energy production divided by the corresponding durations.

4.2.4 Statistical Analysis

All data were presented with mean and standard deviations (M ± SD). One way ANOVAs were performed among four gender and distance conditions for different relative energy production, absolute energy production, and power. Bonferroni correction was used to control the family-wise type-I error. Fifteen ANOVAs were preformed, so a type-I error rate was set at 0.0033 for significant ANOVAs. Type-I error rates were set at 0.05 for significant post-hoc comparisons. Statistical analysis was performed using IBM SPSS Statistics 19 (SPSS Statistics 19, IBM Corporation, New York, USA).

4.3 Results

The ANOVAs showed significant effects among four gender and distance conditions for different absolute relative energy production, absolute energy production, normalized energy production, and power ($p < 0.001$). Post-hoc analysis showed that W_{PCR} % and W_{BLC} % in 40 s-F and 40 s-M were greater than those in 120 s-F and 240 s-M (41.1 % vs. 21.0 % in females, 38.0 % vs. 13 % in males). W_{AER} % in 40 s-F and 40 s-M were less than those in 120 s-F and 240 s-M (31.1 % vs. 58.0 % in female, 32.0 % vs. 76.0%) (Figure 4-1).

W_{PCR} in 40 s-F was less than that in 40 s-M (31.0 kJ vs. 41.0 kJ). W_{BLC} in 40 s-F was less than that in 120 s-F (20.8 kJ vs. 34 kJ). W_{AER} in 40 s-F and 40 s-M were less than those in 120 s-F and 240 s-M (23.4 kJ vs. 92 kJ in females, 35 kJ 275 kJ in males). W_{TOT} in 40 s-F was less than that in 40 s-M (75.2 kJ vs. 108.0 kJ). W_{TOT} in 40 s-F and 40 s-M was less than those in 120 s-F and 240 s-M (75.2 kJ vs. 160 kJ in females, 108 kJ vs. 362 kJ) (Figure 4-2).

When normalized to body mass, $W_{BLC}N$ in 40 s-F was less than that in 40 s-M (0.32 kJ/kg vs. 0.43 kJ/kg). $W_{BLC}N$ in 40s-M was less than that in 240 s-M (0.43 kJ/kg vs. 0.54 kJ/kg). $W_{AER}N$ in 40 s-F and 40 s-M were less than those in 120 s-F and 240 s-M (0.36 kJ/kg vs. 1.43 kJ/kg in females, 0.47 kJ/kg vs. 3.77 kJ/kg in males). $W_{TOT}N$ in 40 s-F and 40 s-M were less than those in 120 s-F and 240 s-M (1.15 kJ/kg vs. 2.47 kJ/kg in females, 1.45 kJ/kg vs. 4.93 kJ/kg).

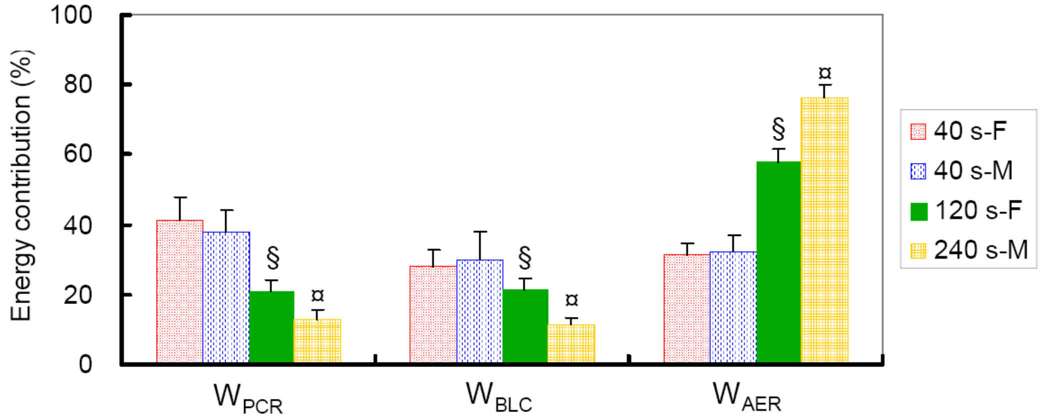

Figure 4-1: Relative energy contributions from anaerobic alactic system (W_{PCR}), anaerobic lactic system (W_{BLC}) and aerobic system (W_{AER}) in 40 s, 120 s and 240 s maximal kayaking; [§] significant from 40 s-F; [¤] significant from 40 s-M; raw data see Appendix 8

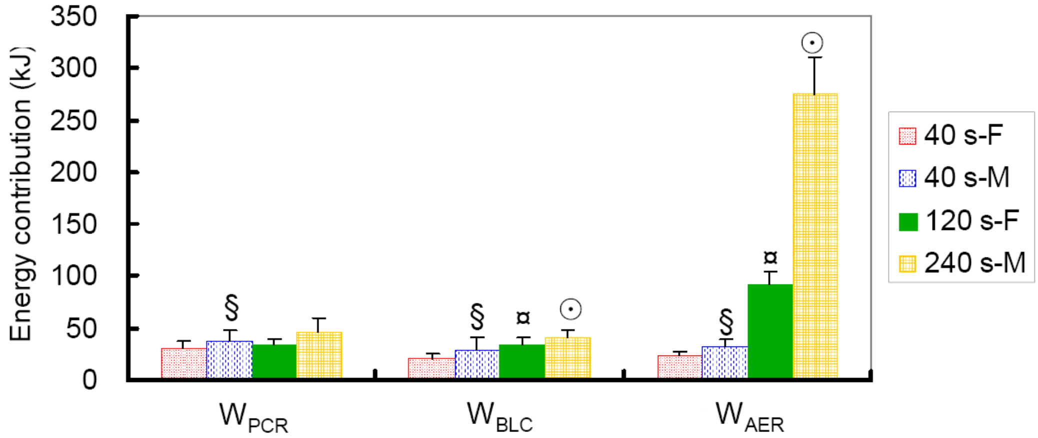

Figure 4-2: Energy contributions from anaerobic alactic system (W_{PCR}), anaerobic lactic system (W_{BLC}), and aerobic system (W_{AER}) in 40 s, 120 s, and 240 s maximal kayaking; [§] significant from 40 s-F; [¤] significant from 40 s-F; [⊙] significant from 40 s-M; raw data see Appendix 8

E_{PCR} and E_{BLC} in 40 s-F were less than that in 40 s-M (0.77 kW vs. 1.03 kW, 0.52 kW vs. 0.81 kW) but greater than those in 120 s-F (0.77 kW vs. 0.28 kW, 0.52 kW vs. 0.28 kW). E_{PCR} and E_{BLC} in 40 s-M were greater than that in 240 s-M (1.03 kW vs. 0.19 kW, 0.81 kW vs. 0.17 kW). E_{AER} in 40 s-F was less than that in 120 s-F (0.59 kW vs. 0.77 kW). E_{AER} in 40 s-M was less than that in 240 s-M (0.87 kW vs. 1.15 kW). E_{TOT} in 40 s-F were less than that in 40 s-M (1.88 kW vs. 2.71 kW) but greater than that in 120 s-F (1.88 kW vs. 1.33 kW). E_{TOT} in 40 s-M was greater than that in 240 s-M (2.71 kW vs. 1.51 kW) (Figure 4-3).

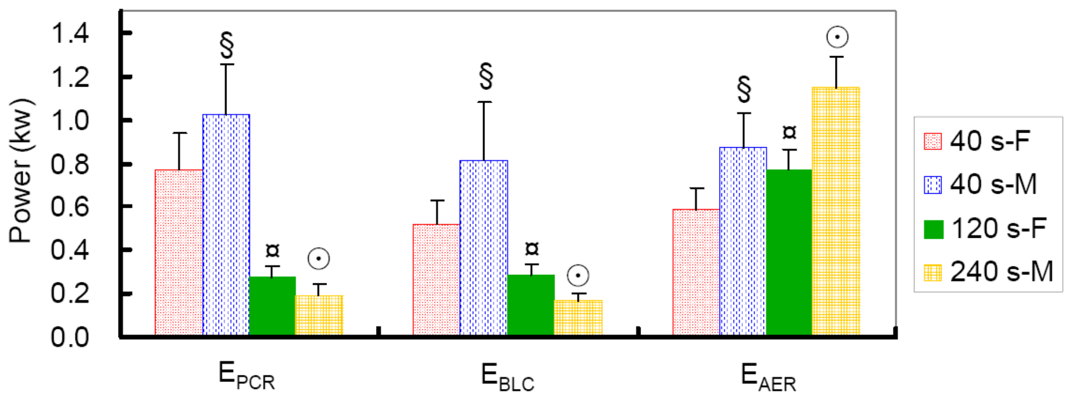

Figure 4-3: Powers from anaerobic alactic system (E_{PCR}), anaerobic lactic system (E_{BLC}), and aerobic system (E_{AER}) in 40 s, 120 s and 240 s maximal kayaking; [§] significant from 40 s-F; [¤] significant from 40 s-F; [⊙] significant from 40 s-M; raw data see Appendix 8

Because the physiological and ergometric measurements were recorded breath by breath or stroke by stroke, the time-series data were obtained and presented in Figure 4-4. The power increased steeply from the start and reached its peak value at about 5 s and decreased slowly until the end for all the durations except for 240 s, in which there was an end spurt. The speed and stroke rate showed a similar process as power except for a later peak point (at about the 10 s). Comparatively, VO_2 and heart rate experienced a fast component of increase to their 90 % of peak values during the first 25–45 s and 15–35 s, respectively, and they continued to increase slowly until the end.

4.4 Discussion

The current study investigated the energetic profiles of simulated female 200 m, female 500 m, male 200 m, and male 1000 m maximal paddling tests on a kayaking ergometer. We demonstrated specific energetic profiles for these four conditions (Figure 4-1–4).

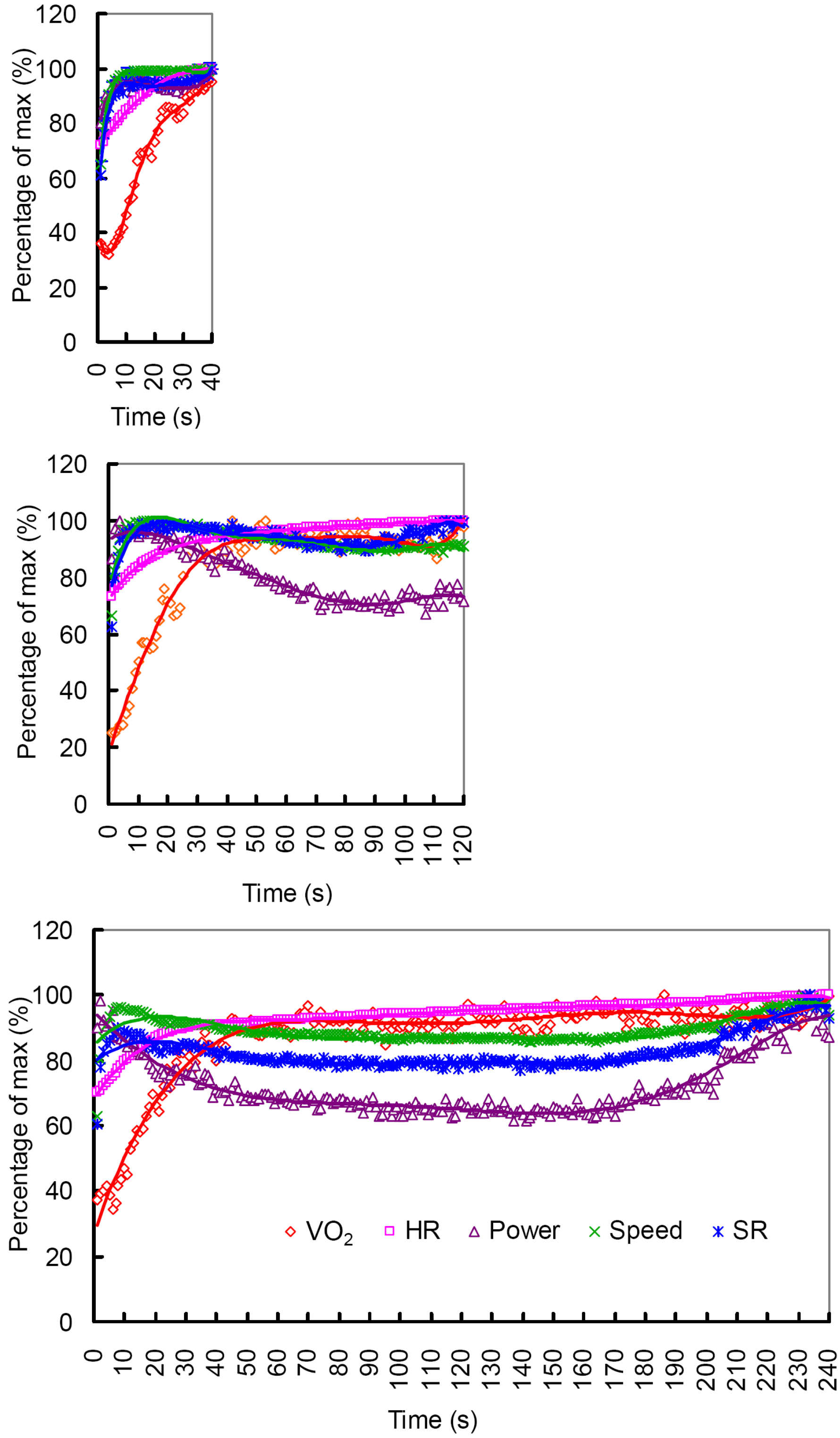

Figure 4-4: Physiological and ergometric process of 40 s, 120 s, and 240 s maximal kayaking (top panel for 40 s in females and males, N = 29; middle panel for 120 s in females, N = 15; bottom panel for 240 s in males, N = 12. raw data see Appendix 9, figure with SD see Appendix 10)

First, the 500 m and 1000 m tests were aerobic dominant, with W_{AER} % of 57.8 ± 3.9 % and 76.2 ± 3.9 %. The 200 m was anaerobic dominant, with W_{AER} % of 31.1 ± 3.4 % in females and 32.4 ± 4.6 % in males. The findings of

W_{AER} % were consistent with those of other reports, which indicated the validity of the energy calculating method introduced by Beneke et al. Among the reported findings, the W_{AER} % levels were 29–40 % in 40 s (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008), 57–69 % in 120 s (BISHOP, 2000; BISHOP ET AL., 2001, 2002; BISHOP ET AL., 2003; BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008), and 74–86 % in 240 s (BYRNES & KEARNEY, 1997; NAKAGAKI ET AL., 2008). However, the W_{AER} % in this study was in the lower ranges compared to other similar investigations (BYRNES & KEARNEY, 1997; ZOUHAL ET AL., 2012). The relatively higher W_{AER} % in other studies might result from an underestimate of anaerobic energy production, and thus an overestimate of W_{AER} % with the method utilized (MAOD) (BANGSBO, 1992, 1998) (also see Chapter 2 and 3). However, Nakagaki et al. (2008) used the same method as Byrnes and Kearney (1997) (both MAOD) but reported a series of W_{AER} % levels closer to the findings in this study. Therefore, MAOD might not be the most reliable method in calculating the anaerobic energy (DOHERTY & SMITH, 2001), or some other possible factors (e.g., motivation and muscle fiber composition, see Chapter 3) might also have influence the W_{AER} % findings. On the contrary, Zamparo et al. (1999) demonstrated a W_{AER} % of 41 % in 250 m (62 s), 60 % in 500 m (134 s), and 83 % in 1000 m (289 s) using a method based on the three pathways of energy contribution introduced by Wilkie (1980), similar to the method in this study. Given that the W_{AER} % in maximal or maximal exercises is relevant to the duration (GASTIN, 2001), the W_{AER} % levels in this study were in line with those from Zamparo et al. Additionally, the subjects in the present study were junior kayakers with a training experience of only 4 to 36 months. The limited experience might have had an influence on W_{AER} %, but this possibility was excluded based on the study in Chapter 3. The pacing strategy was not required in this study, because similar W_{AER} % was reported in 2 min maximal kayaking with two different pacing strategies (all-out start vs. even) (BISHOP ET AL., 2002). Actually, all of the paddlers in this study reached their peak power during their first 5 to 10 s (Figure 4-4), which appeared more to be an all-out start strategy.

Second, the results indicated that the energetic profile depended on the durations of maximal exertions and the involved muscle groups. Paddlers produced greater W_{AER} % in longer durations. However, W_{PCR} % results were similar between shorter and longer durations for both males and females. The similar W_{PCR} % results were because of the determination of ATP-CP by muscle mass (20–25 mM per kilogram wet muscle (GREENHAFF ET AL., 2004)), and fast depletion of ATP-CP during the first 5–10 s. As shown in Figure 4-4, the power, speed, and stroke rate peaked at 5–10 s. Although W_{BLC} % results were also significantly greater in longer durations, the differences were relative small compared to those of W_{AER} %. The subjects in this study were juniors trained mostly with long distances. It might have been difficult for them to exert their maximum capacity in short-duration exertion. Therefore, their peak blood lactate in 40 s was much less as compared to world-elite 200 m paddlers (7.9 ± 1.8 mM vs. 13-15 mM) (NIKONOROV, 2012), who could produce as much blood lactate as in 500 m and 1000 m but in much shorter time. Actually, the amount of W_{BLC} also depended on muscle mass (50 mM per kilogram wet muscle (GREENHAFF ET AL., 2004)). The difference between the two durations for both genders in this study did disappear as W_{BLC} % results were relative to body mass. Given that both genders in this study performed 40 s maximal paddling, it was possible to investigate the influence of muscular volume on energetic profile in kayaking. Although males produced significantly more energy from all three pathways (Figure 4-2), the significance did not exist anymore when the energy contributions were relative to body mass.

Third, the characteristic of power output in three energy pathways indicated different energetic demands in different durations. The longer duration generated a higher demand of aerobic power output, whereas the shorter duration needed a higher demand of anaerobic power output, conversely. The findings provided physiological insight into training in 200 m, 500 m, and 1000 m. Training documentation from German national teams indicated an agreement between physiological functions and the training in practice. About 85–88 % of training on water was performed with an intensity of < 4 mM blood lactate throughout the four years' Olympic preparation (ENGLERT & KIESSLER, 2009). A report on the Spanish national team in preparing for the world championship indicated a yearly water training volume of 4415 km, in which > 80 % was trained with the intensity of < 4 mM blood lactate

(GARCIA-PALLARES ET AL., 2010). However, it was found that the 200 m male finalists in the London Olympic Games were 2.0 kg heavier than the 1000 m male finalists, on average, even though they were 2.0 cm shorter (LI, 2012). As mentioned previously, a heavier body mass (mostly as muscle mass) could bring a higher capacity of anaerobic energy supply (GREENHAFF ET AL., 2004).

Last, the physiological and energetic process could provide the interactions between the three energy systems in 200 m, 500 m, and 1000 m. The anaerobic alactic system determined the total energy production during the first 5–10 s, while the aerobic system had nearly not been used for all distances (see VO_2 in Figure 4-4). At the same time, the anaerobic lactic system had not reach its maximal metabolism rate (GLADDEN, 2004; MADER, 2003). The power as well as speed and stroke rate reached their peak value. This phenomenon could also be found in simulated rowing races (HARTMANN ET AL., 1993). With regard to the aerobic system, its dominance in total energy supply started only from the 30–40 s, when the VO_2 reached its 90 % peak value (Figure 4-4). The vacancy between the 5–10 s and 30–40 s could only be filled by the anaerobic lactic system. This energetic profile could provide physiological support for developing the training philosophy in these three distances.

4.5 Conclusion

Energetic profiles in kayaking varied with paddling distances. At 500 m and 1000 m distances, the aerobic system was dominant (with W_{AER} % of 57.8 % and 76.2 %), whereas, at 200 m, the anaerobic system was dominant (with W_{AER} % of 31.1-32.4 %). Muscular volume seemed to have an influence on absolute energy production. The anaerobic alactic system determined the performance during the first 5 to 10 s. Anaerobic lactic system probably played a dominant role during the period from the 5–10 s to 30–40 s. The aerobic system could dominate the energy contribution after 30–40 s. This energetic profile in kayaking could provide physiological support for developing the training philosophy in these three distances. Additionally, the method introduced by Beneke et al. seemed to be a valid method to calculate the energy contributions in maximal kayaking.

5 Energetics of Canoeing at Submaximal and Maximal Speeds

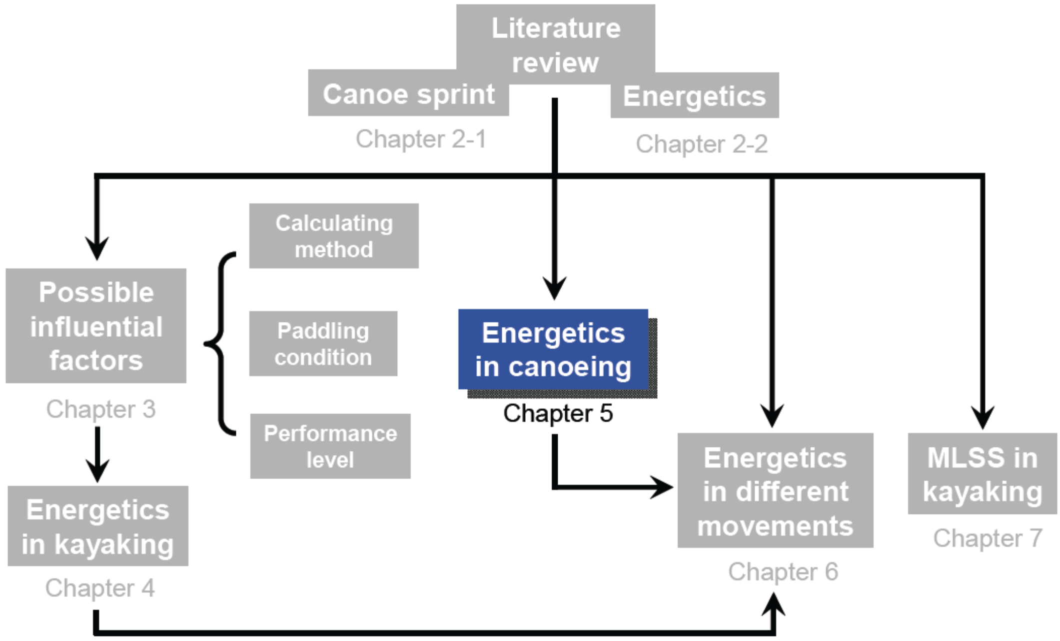

Illustration of the research design - Chapter 5

5.1 Introduction

Investigations on the energetics of canoeing started as early as the 1920 s (WOHLFEIL, 1928). Seliger et al. reported the energy expenditures in 1000 m paddling canoeing when subjects were sitting on a seat (SELIGER ET AL., 1969). More recent investigations on the energetics of canoeing were reported in the 1990s (DAL MONTE ET AL., 1993; MISIGOJ-DURAKOVIC & HEIMER, 1992). The energy contributions of canoeing on an ergometer were investigated for the first time in 1997 (BYRNES & KEARNEY, 1997). It was found that the W_{AER} % results were 36.5 %, 63.5 %, and 84.5 % for 200 m, 500 m, and 1000 m, respectively (BYRNES & KEARNEY, 1997).

The amount of energy above the resting level spent per unit of distance was defined as C (CERRETELLI & DI PRAMPERO, 1990). C has been widely investigated in running (ANTONUTTO ET AL., 1993; BRUECKNER ET AL., 1991; DI PRAMPERO ET AL., 1986), swimming (ZAMPARO ET AL., 2011), gondola (CAPELLI ET AL., 1990), and kayaking (ANTONUTTO ET AL., 1999; BUGLIONE ET AL., 2011; PENDERGAST ET AL., 1989). Only a few investigators have evaluated C in canoeing (BUGLIONE ET AL., 2011). Differences in C have been found among a variety of locomotion types (CERRETELLI & DI PRAMPERO, 1990). Although kayaking and canoeing are upper-body dominant sports (SHEPHARD, 1987), the difference of C between them was still unknown. Therefore, the objective of this study is to investigate the energetics of canoeing on open water at submaximal and maximal speeds. We hypothesized that energy contributions and C in canoeing would be similar to those in kayaking.

5.2 Methods

5.2.1 Subjects

Eight healthy male canoeists volunteered to participate in this study. All subjects were national medalists in national championships of adult or junior groups during the past three years. The anthropometric and physiological characteristics of the subjects are shown in Table 5-1. Subjects signed informed consent forms prior to participation. The study was conducted according to the corresponding ethics requirement.

5.2.2 Procedures

Energy contributions during submaximal and maximal paddling were calculated based on the method implemented by Beneke et al. (2004; 2002). C of canoeing on open water was also calculated thereafter. The tests were performed on two separate days (08:00-12:00, and 14:00-18:00) at the beginning of subjects' competitive season (three days of transitional training after the spring regatta). The tests were performed with individuals' racing boats. Subjects were familiar with the experimental procedure. The tests were performed with absence of wind. The altitude, pressure, temperature, and humidity during the tests were 8 m, 1001–1006 mbar, 22–27 °C, and 72–78 %, respectively.

Table 5-1: Anthropometric and physical characteristics of subjects

Subject	Age	Height	Weight	VO_{2peak}*		Training Experience
	[yrs]	[cm]	[kg]	[l/min]	[ml/min/kg]	[yrs]
1	27	177	83.6	4.5	54	10
2	25	181	79.4	4.6	58	9
3	21	183	83.9	5.2	62	8
4	17	178	75.6	4.1	55	5
5	19	178	74.3	4.2	56	6
6	19	180	79.3	4.7	59	6
7	19	183	77.0	5.0	65	4
8	19	180	81.4	4.6	57	6
Mean ± SD	21 ± 3	180 ± 2.3	79.3 ± 3.5	4.6 ± 0.4	58.3 ± 3.7	6.8 ± 2.1

* VO_{2peak} = peak VO_2, averaged continuous 30 s in 4 min maximal paddling

5.2.3 Paddling at Maximal Speed

Subjects were not allowed to take any food except for drinks two hours prior to tests. A typical diet high in carbohydrates was adhered to by the subjects before the tests. The maximal test included a 10 min self-controlled warm-up, a 5 min rest, and was followed by a 4 min maximal paddling session on open water. Subjects used self-chosen pacing strategies to mimic the racing condition. A portable spirometer (MetaMax 3B, Cortex Biophysic, Leipzig, Germany) was utilized for recorded the breath-by-breath gas from start of warm-up to 10 min after the end of maximal paddling. The pressure, gas, and volume were calibrated for the spirometer using a syringe of 3 l and a gas of known composition (O_2, 15.00 %; CO_2, 5.00 %). A heart monitor (Polar Accurex Plus, Polar Electro Oy, Kempele, Finland) was used throughout the test. 20 µL blood was taken from earlobe before the warm-up, immediately after the warm-up and before the maximal paddling, and at the 1st, 3rd, 5th, 7th, and 10th min during the recovery. The blood samples were analyzed using a lactate analyzer (Biosen S_line, EKF Diagnostic, Barleben, Germany). Boat speed was monitored by a GPS (Forerunner 301, Garmin, Olathe, Kansas, USA) located on the boat. The spirometric data were sent telemetrically from the portable knapsack located on the back of paddlers to a personal computer transported by a car on the bank of 2000 m standard regatta course. The data of boat speed were downloaded to the computer after the tests.

5.2.4 Paddling at Submaximal Speed

The submaximal paddling was performed on the second day after the maximal paddling. The tests consisted of four 5 min paddling sessions with 10 min rest in between. The four tests included 75 %, 80 %, 85 %, and 90 % of individual maximal speed, which was similar to the step test used by the German Canoe/Kayak Association (4 × 1000 m) (ENGLERT & KIESSLER, 2009). The use of spirometer, heart rate monitor, blood taking, as well as boat speed was the same as in maximal paddling. However, the time of blood sampling was prior to the 1st step, and 1st, 3rd, 10th min between each two steps, as well as the 1st, 3rd, 5th, 7th, and 10th min during the recovery after the last step. Subjects were informed of their speeds for each step and required to strictly follow the designed speeds. The actual speeds for all the subjects during the step test were on average 75 %, 79 %, 83 %, and 88 % of maximal speed.

5.2.5 Calculating the Energy Contributions

The energy consumptions were calculated according Beneke et al. (2004; 2002). The total consumed energy (W_{TOT}, in kJ) included anaerobic alactic

(W_{PCR}, in kJ), anaerobic lactic (W_{BLC}, in kJ), and aerobic contribution (W_{AER}, in kJ), as function:

$$W_{TOT} = W_{PCR} + W_{BLC} + W_{AER}$$

W_{PCR} was estimated from the fast component of oxygen debt during the recovery (KNUTTGEN, 1970; MARGARIA ET AL., 1933a; ROBERTS & MORTON, 1978). W_{PCR} was methodologically determined by two exponential equations (3 min fast component and 3 min slow component) (BENEKE ET AL., 2004; BENEKE ET AL., 2002); W_{BLC} was estimated from the net blood lactate with the assumptions that an oxygen-lactate was equivalent 3.0 $ml \cdot kg^{-1} \cdot mmol^{-1} \cdot l$ and a distribution space of lactate of approximately 45 % of the body mass (DI PRAMPERO, 1981); W_{AER} was estimated from the time integral of VO_2 during paddling based on a resting level of 4.0 ml O_2 $kg^{-1} \cdot min^{-1}$ (CIBA-GEIGY, 1985). Given the caloric equivalents of oxygen at difference respiratory quotients (R.Q.) (STEGMANN, 1977), each part of energy with a unit of oxygen could be calculated into kJ. All three parts of energy were considered for maximal paddling. The anaerobic lactic and aerobic share energy was considered for submaximal paddling, because anaerobic alactic energy could be ignored for submaximal paddling (ANTONUTTO ET AL., 1999; ANTONUTTO ET AL., 1993; BENEKE & HUTLER, 2005). The absolute C of submaximal and maximal canoeing was then divided by the total paddling distance (in meter).

5.2.6 Statistical Analyses

All of the data in this study were described with mean ± SD.

5.3 Results

The energetic results of submaximal and maximal paddling are provided in Table 5-2. R.Q. was the average of all steps in submaximal paddling and maximal paddling. An individual caloric equivalent of oxygen was to calculate energy according to Stegemann (1977). When the R.Q. was ＞1.0 in maximal paddling, a caloric equivalent of 21.131 $J \cdot ml^{-1}$ was utilized.

Table 5-2: Energetic results of submaximal and maximal paddling (N = 8)

		1st Step	2nd Step	3rd Step	4th Step	Maximal
Time	[min]	5	5	5	5	4
Speed	[m/s]	2.99 ± 5.00	3.13 ± 0.09	3.28 ± 0.08	3.50 ± 0.14	3.97 ± 0.14
Distance	[m]	896 ± 16	927 ± 27	987 ± 25	1102 ± 42	954 ± 35
Acc. VO_2	[l]	12.5 ± 0.5	13.9 ± 0.8	15.6 ± 1.1	18.9 ± 1.9	16. 9 ± 1.3
Net blood lactate	[mM]	0.20 ± 0.19	0.25 ± 0.39	0.57 ± 0.44	3.33 ± 2.42	10.09 ± 1.53
VO_{2PCR}	[l]	/	/	/	/	2.759 ± 0.545
R.Q.		0.81 ± 0.02	0.86 ± 0.03	0.86 ± 0.03	0.94 ± 0.04	1.07 ± 0.05
W_{PCR}	[kJ]	/	/	/	/	58.3 ± 13.3
W_{BLC}	[kJ]	1.0 ± 0.9	1.3 ± 2.0	2.8 ± 2.1	16.6 ± 12.3	50.9 ± 9.0
W_{AER}	[kJ]	216.0 ± 8.8	260.8 ± 37.7	281.4 ± 22.5	353.2 ± 37.4	326.9 ± 26.6
W_{TOT}	[kJ]	216.9 ± 9.0	262.1 ± 38.4	284.2 ± 23.6	369.8 ± 46.8	436.1 ± 41.2
W_{PCR}	[%]	/				13.3 ± 1.9
W_{BLC}	[%]	0.4 ± 0.4	0.5 ± 0.7	1.0 ± 0.7	4.3 ± 2.8	11.6 ± 1.2
W_{AER}	[%]	99.6 ± 0.4	99.5 ± 0.7	99 ± 0.7	95.7 ± 2.8	75.1 ± 2.8
C	[kJ/m]	0.24 ± 0.01	0.28 ± 0.04	0.29 ± 0.02	0.35 ± 0.03	0.46 ± 0.03

Acc. VO_2 = accumulated VO_2 during paddling; net blood lactate = peak blood lactate above pre-paddling level; VO_{2PCR} = fast component of oxygen debt above rest level; R.Q. = respiratory quotient; W_{PCR} = anaerobic alactic energy; W_{BLC} = anaerobic lactic energy; W_{AER} = aerobic energy; W_{TOT} = total energy; C = energy cost

The VO_2 in last 2 min of each step was averaged during submaximal paddling, and it represented the steady state VO_2 for each step. The VO_2 as a function of speed is described in Figure 5-1. The C in submaximal and maximal paddling was provided as a function of speed (Figure 5-2), with a function of $y = 0.0242 * x^{2.1225}$ ($R^2 = 0.8815$).

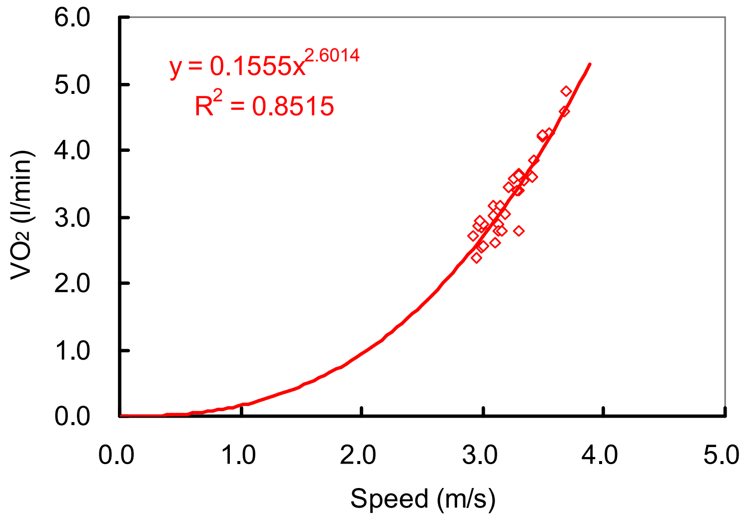

Figure 5-1: VO_2 as a function of speed (data from all of the participants in submaximal paddling, N = 32, raw data see Appendix 11)

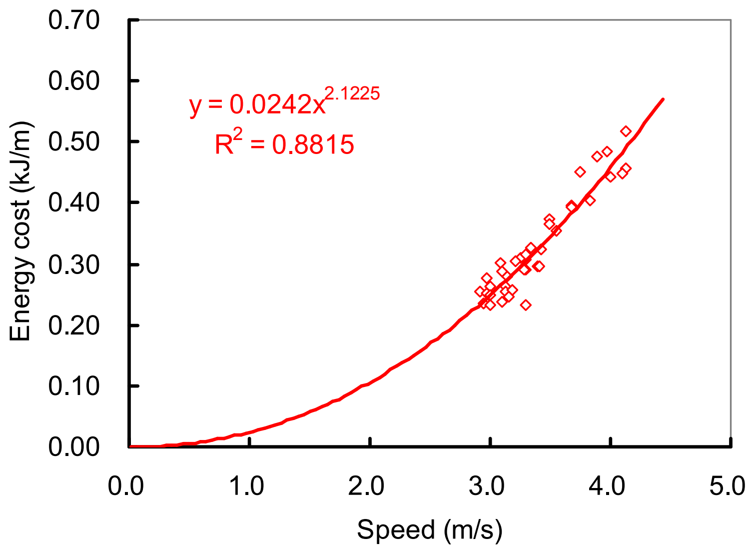

Figure 5-2: C as a function of speed (data from submaximal and maximal paddling, N = 40, raw data see Appendix 11)

5.4 Discussion

Studies on energetics in canoeing are few compared to those in kayaking. In the current study, we found that the relative energy contributions from three pathways in 4 min maximal paddling were 13.2 ± 1.9 % (W_{PCR}), 11.5 ± 1.2 % (W_{BLC}), and 75.3 ± 2.8 % (W_{AER}). The W_{AER} % was in the lower range of previously reported results in kayaking and canoeing with the same duration (ANTONUTTO ET AL., 1999; BYRNES & KEARNEY, 1997; NAKAGAKI ET

AL., 2008). Byrnes and Kearney investigated American national kayakers and canoeists on an ergometer and demonstrated a range of 81–92 % for 4 female kayakers and a range of 81–88 % for 2 canoeists (BYRNES & KEARNEY, 1997). Nakagaki et al. reported a 74 % in 8 university males in kayaking on an ergometer (NAKAGAKI ET AL., 2008). The method of calculating energy used by Byrnes and Kearney (MAOD, as introduced by Medbo et al. (1988)) could lead to an overestimate of W_{AER} % when compared with the method used in the current study. The overestimation was supported by Bangsbo (1998). Additionally, using a similar method as in the current study, Zamparo et al. (1999) found a W_{AER} % of 83 % in 4 female and one male kayakers with middle to high level paddling on water for a duration of 289 s. It was postulated that the W_{AER} % in 240 s could be lower than 83 % if the subjects in Zamparo et al.'s study paddled 240 s instead of 289 s, because the W_{AER} % increased with duration of maximal exercise (GASTIN, 2001). Therefore, the lower level of W_{AER} % in this study could also be explained by the methods of calculating energy. Additionally, the limited number of subjects in Byrnes and Kearney's study might have an influence on their results. A greater aerobic power was found in this study (18.4 watt·kg^{-1}) than the results reported by Nakagaki et al. (16.6 watt·kg^{-1}) (2008) with no difference in anaerobic power (both 5.7 watt·kg^{-1}).,The W_{AER} % results were close (75.3 % vs. 74.0 %) in both investigations, but an overestimate of W_{AER} % might exist in the study of Nakagaki et al. (2008) as mentioned previously.

An exponent increase of VO_2 as a function of speed was found in this study (Figure 5-1), which was in line with other sports (NOZAKI ET AL., 1993; PUGH, 1974; SECHER, 1992). As described in Table 5-1, the energy supply during the submaximal paddling was dominated by the aerobic pathway (> 99 %), which made it reasonable to find a net blood lactate of < 1 mM after each of the first three steps. In other words, the increase of speed up to 3.3 ± 0.08 m/s (83 % of average speed in 4 min maximal paddling) could be maintained aerobically. The upper range of speed here was higher than that in paddling with slalom boats (2.2 m/s), which resulted probably from the higher efficiency of sprint canoe boats (PENDERGAST ET AL., 1989). The findings supported the design of step test used in the German Canoe/Kayak

Association, in which the 4 mM was supposed to appear between 80 % and 85 % of the average speed in 1000 m maximal paddling (KAHL, 2005).

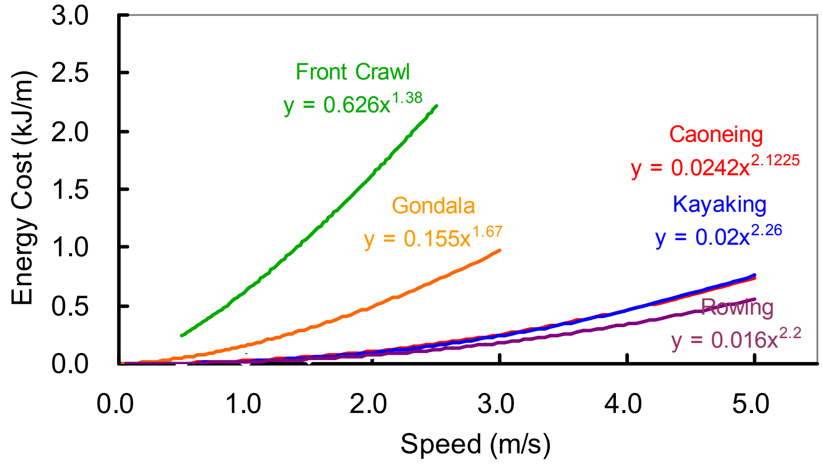

Figure 5-3: Comparison of C in different locomotion; data from front crawl (CAPELLI ET AL., 1998), gondola (CAPELLI ET AL., 1990), kayaking (ZAMPARO ET AL., 1999), rowing (DI PRAMPERO ET AL., 1971), and canoeing (own data from this study), raw data see Appendix 12

The C of canoeing in this study increased with the increase of speed as demonstrated by a function with an exponent of 2.1225 (Figure 5-2). The exponent was among the previous reported exponents ranging from 1.38 to 2.26 (ALIVERTI ET AL., 2009; ANTONUTTO ET AL., 1999; CAPELLI ET AL., 1990; CAPELLI ET AL., 1998), but this was the first time it was applied to sprint canoeing. Buglione et al. attempted to draw the relationship between C and speed for canoeing, but a lack of steps limited their ability to quantify the relationship (BUGLIONE ET AL., 2011). When comparing with kayaking, we found that the C of canoeing was similar to the findings by Zamparo et al. (1999), who reported an exponent 2.26 in kayaking (Figure 5-3). When compared with rowing, the yearly training volume on water was much lower in canoeing and kayaking (3000–4200 km) (GARCIA-PALLARES ET AL., 2009) than in rowing (5827–7500 km) (GARCIA-PALLARES ET AL., 2009; HARTMANN & MADER, 2005). The efficiency was also reported lower in canoeing and kayaking (13–17 %) than in rowing (20 %) (BUNC & HELLER, 1994; HOFMIJSTER ET AL., 2009). Although there was no cross-sectional comparison of C between canoeing and kayaking, the findings in the current study demonstrated a similar C between canoeing and kayaking.

5.5 Conclusion

The relative energy contributions on open water canoeing were 75.3 ± 2.8 % of aerobic, 11.5 ± 1.9 % of anaerobic lactic, and 13.2 ± 1.9 % of anaerobic alactic at maximal speed of 4 min, which was similar to those reported in kayaking. The C of canoeing seemed also to be similar to that in kayaking. A training program could be designed similarly for kayaking and canoeing with regard to energetic profile.

6 Aerobic Energy Contribution in Selected Movement Patterns

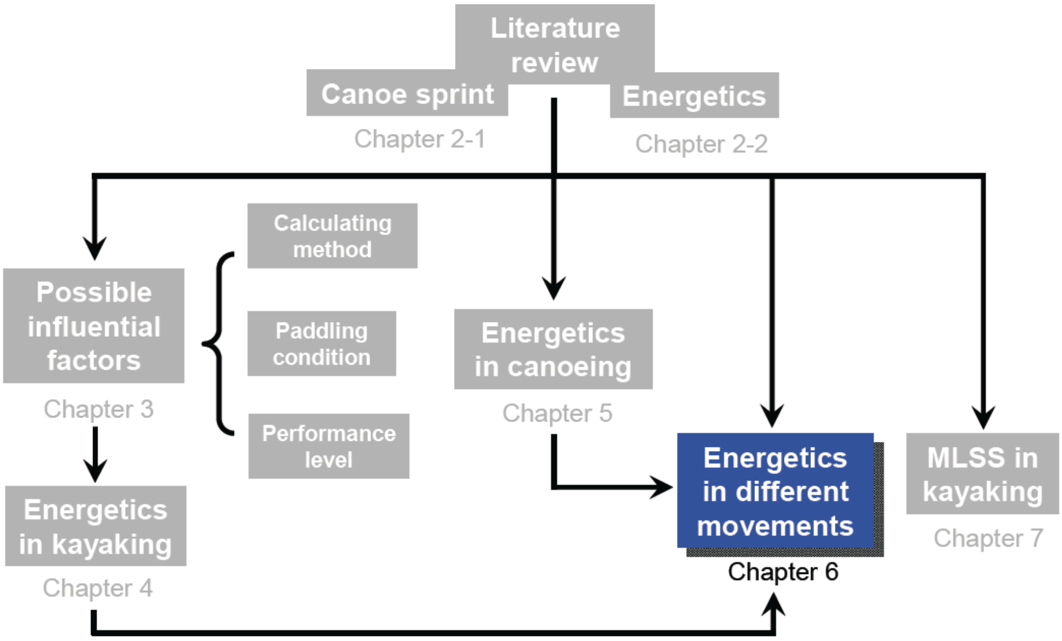

Illustration of the research design - Chapter 6

6.1 Introduction

Investigations on aerobic energy contribution in maximal exertions have been documented as early as 1970 in the textbook of Astrand and Rodahl, where the aerobic and anaerobic energy contributions in exercises involving large muscles were provided as a table (ASTRAND & RODAHL, 1970). As Astrand and Rodahl's table (1970) became widespread, aerobic energy contribution was studied independently in a variety of movement patterns, such as rowing (HARTMANN, 1987; MADER & HOLLMANN, 1977), cycling (GASTIN, P.B. & LAWSON, D.L., 1994; MEDBO & TABATA, 1993), running (DUFFIELD ET AL., 2005b; SPENCER & GASTIN, 2001), kayaking (ABENAVOLI ET AL., 2001; BISHOP, 2000), etc. However, an underestimate of W_{AER}% in Astrand and Rodahl's table was consistently found by many studies (GASTIN, 2001) (and see Chapter 2 and 3). An exponential correlation between W_{AER} % and duration in maximal exercises was found by summarizing the literature (GASTIN, 2001) (also see Chapter 2).

However, the variations of W_{AER} % in different studies could not be ignored. For example, the W_{AER} % varied from 50.6 % (116 s) (HETTINGA ET AL., 2007) to 70.3 % (120 s) (BISHOP, 2000) in approximate 120 s maximal exercises among different studies. The variations were also observed in other durations of maximal effort (GASTIN, 2001) (also see Chapter 2). Some other factors besides the duration might also affect W_{AER} %. The method used in calculating the energy contribution could be one possible factor (see Chapter 3). The method of MAOD introduced by Medbo et al. (1988) could result in an overestimate of W_{AER} % (BANGSBO, 1992, 1998; BANGSBO ET AL., 1990). Another possible factor that might affect energy contribution is the movement pattern used during maximal exertion. MLSS varies according to the muscular mass involved in exercises (BENEKE, 2003b). However, it was still unknown whether the movement pattern could influence W_{AER} % in maximal exercises.

The objective of this study is to examine whether movement patterns had influence on W_{AER} % in exercises of maximal effort. It was hypothesized that movement pattern might influence the W_{AER} % during maximal exertion with the same duration.

6.2 Methods

6.2.1 Subjects

Three groups of participants volunteered to perform one or three maximal exertions in this study (Table 6-1). Group 1 (G1, N = 9, males) and group 2 (G2, N = 8, males) were from a kayaking and canoeing team of national level, respectively. Group 3 (G3, N = 24, 7 females and 17 males) included amateur long-distance runners, cyclists, and triathletes. Most of participants in G3 trained 3–6 h per week. The study was conducted according to the corresponding ethic requirement. Subjects signed an informed consent form prior to participation.

Table 6-1: Characteristics of three groups of participants

	Height	Mass	Age	VO_{2peak}*		Training Experience
	[cm]	[kg]	[yrs]	[l/min]	[ml/min/kg]	[yrs]
G1	189 ± 3†	85 ± 6†	21 ± 3	4.614 ± 0.434†	54.6 ± 5.8	5.3 ± 2.0
G2	180 ± 2	79 ± 4†	21 ± 3	4.616 ± 0.371†	58.2 ± 3.8	6.8 ± 2.1
G3	177 ± 10	73 ± 11	33 ± 9	4.115 ± 0.735‡	56.1 ± 8.0‡	11.4 ± 9.5

* VO_{2peak} = peak VO_2; peak averaged 30 s VO_2 in 4 min maximal exercises; † significant from G3 ($p < 0.05$); ‡ significant from running

6.2.2 Procedures

G1 and G2 performed a maximal kayaking and a maximal canoeing session on water with racing boats on a 2000 m racing course, respectively. G3 performed three maximal exercises, including running on a 400 m round athletics field, cycling on an electromagnetic braked cycle ergometer (Lode Excalibur Sport, Lode., BV, Groningen, The Netherlands), as well as arm cranking with a stationary arm crank ergometer (Ergoline 800SH, Pilger Medizin-Elektronik, Ergoline, Bitz, Germany). The movement frequency was kept at approximate 90 rpm and 70 rpm for cycling and arm cranking, respectively. Because the finishing time for 1000 m kayaking and canoeing is approximate 4 min and W_{AER} % is dependent on the duration of maximal exercises (see Chapter 2), the duration of maximal exercises in this study was fixed at 4 min for all the three groups. Subjects performed 10 min warm-up with self-chosen intensity and a 5 min passive rest, followed by 4 min maximal exercises with spoken encouragement.

Subjects were not allowed to perform intensive training one day before the testing or take food two hours before testing. A typical diet high in carbohydrate was adhered to by the subjects before the tests. At least a 24 h interval was given to G3 between each of the two tests. All of the testing was finished in at most one month. A portable spirometer (MetaMax 3B, Cortex Biophysic, Leipzig, Germany) was calibrated before each testing day and utilized to measure oxygen intake continuously. From the subjects' earlobes, 20 μL capillary blood was taken before the warm-up, immediately after the warm-up, before the maximal exercises during the passive rest, and at 1st, 3rd, 5th, 7th, and 10th min during the recovery after the maximal trials. The analysis of blood lactate was performed using a lactate analyzer (Biosen S_line, EKF Diagnostic, Barleben, Germany). A heart rate monitor (Polar Accurex Plus, Polar Electro Oy, Kempele, Finland) was utilized. The temperature, air pressure, and humidity were 15–25 °C, 995–1010 mbar, 30–60 %, respectively, for all the groups.

6.2.3 Calculating the Energy Contributions

The methodology implemented by Beneke et al. (2004; 2002) was utilized in calculating energy contribution. Anaerobic alactic energy (W_{PCR}) was calculated from the fast component of oxygen debt after maximal exertions (KNUTTGEN, 1970; MARGARIA ET AL., 1933a; ROBERTS & MORTON, 1978). The anaerobic lactic energy (W_{BLC}) was calculated from net blood lactate in maximal exercises, with an oxygen-lactate equivalent of 3.0 $ml \cdot kg^{-1} \cdot mmol^{-1} \cdot l$ (DI PRAMPERO, 1981). The aerobic energy was calculated from the actual accumulated VO_2 (W_{AER}) above rest level, which was fixed at 4.0-4.5 $ml \cdot kg^{-1} \cdot min^{-1}$ for different postures of exercises (CIBA-GEIGY, 1985). The energy contributions of these three components could be calculated into kilojoule with a caloric equivalent of 21.131 $J \cdot ml^{-1}$ (DI PRAMPERO, 1981). Therefore, $W_{TOT} = W_{PCR} + W_{BLC} + W_{AER}$, and $W_{AER}\ \% = 100 \times (W_{AER}/W_{TOT})$. The normalized energy contributions ($W_{PCR}N$, $W_{BLC}N$, $W_{AER}N$, and $W_{TOT}N$) were calculated as the absolute energy contributed divided by body mass.

6.2.4 VO_2 Kinetics

The breath-by-breath gas data were interpolated to second-by-second data before they were aligned to the start of each maximal exercise. Nonlinear regression techniques were used to fit the VO_2 data after the onset of exercise with an exponential function. A mathematical model of three exponential components were utilized (equation 1) (BARSTOW ET AL., 1996):

$$\begin{aligned} VO_2(t) = VO_2(b) &+ A_0*(1-e^{-t/\tau_0}) \quad \text{Phase1 (initial component)} \\ &+ A_1*(1-e^{-(t-TD_1/\tau_1)}) \quad \text{Phase2 (primary component)} \quad (1) \\ &+ A_2*(1-e^{-(t-TD_2/\tau_2)}) \quad \text{Phase3 (slow component)} \end{aligned}$$

where $VO_2(b)$ is the rest baseline value; A_0, A_1, and A_2 are the asymptotic amplitudes for the exponential terms; τ_0, τ_1, and τ_2 are the time constants; and TD_1 and TD_2 are the time delays. The phase 1 term was terminated at the start of phase 2 (i.e., at TD_1) and assigned the value for that time (A_0')

$$A_0' = A_0*(1-e^{-TD_1/\tau_0})$$

6.2.5 Statistical Analysis

One-way ANOVAs were performed for W_{PCR}, W_{BLC}, W_{AER}, W_{TOT}, $W_{PCR}N$, $W_{BLC}N$, $W_{AER}N$, $W_{TOT}N$, τ_1, and W_{AER} % among five movement pattern conditions. Tukey's HSD post-hoc analysis was used when a significant condition effect was found. Pearson correlation test was performed between τ_1 and W_{AER} %. Bonferroni correction was used to control the family-wise type-I error for multiple ANOVAs. Ten ANOVAs were performed, so a type-I error rate was set at 0.005 for significant ANOVAs. Type-I error rates were set at 0.05 for significant post-hoc comparisons and the Pearson correlation test. All statistical analysis was performed using IBM SPSS Statistics 19 (SPSS Statistics 19, IBM Corporation, New York, USA). All data were provided with M and SD.

6.3 Results

ANOVAs showed significant condition effects for W_{PCR}, W_{AER}, W_{TOT}, W_{PCR} N, $W_{AER}N$, $W_{TOT}N$, τ_1, and W_{AER} % (Table 6-2). Post-hoc analysis showed that W_{PCR} in kayaking and canoeing were significantly greater than those in running, cycling, and arm cranking. W_{PCR} in running and cycling were significantly greater than that in arm cranking. W_{AER} in kayaking, canoeing, running, and cycling were significantly greater than that in arm cranking. W_{AER}

Table 6-2: Energy contributions of the five studied movement patterns from three groups

	G1	G2	G3			ANOVA P Values
	Kayaking	Canoeing	Running	Cycling	Arm Cranking	
	M	M	M	M	M	
W_{PCR} [kJ]	60.4 ± 14.6	58.3 ± 11.5	41.0 ± 12.6	38.3 ± 10.5	26.1 ± 7.6	< 0.001
W_{BLC} [kJ]	49.4 ± 8.1	50.9 ± 9.0	42.1 ± 14.5	52.9 ± 18.4	41.9 ± 14.0	0.114
W_{AER} [kJ]	332.2 ± 37.0	330.3 ± 26.7	275.2 ± 53.3	279.0 ± 61.3	151.0 ± 41.3	< 0.001
W_{TOT} [kJ]	442.0 ± 36.0	439.5 ± 41.3	358.4 ± 65.5	370.3 ± 79.4	219.0 ± 59.2	< 0.001
$W_{PCR}N$ [kJ/kg]	0.72 ± 0.21	0.73 ± 0.13	0.56 ± 0.16	0.52 ± 0.15	0.34 ± 0.08	< 0.001
$W_{BLC}N$ [kJ/kg]	0.58 ± 0.09	0.64 ± 0.10	0.57 ± 0.18	0.71 ± 0.19	0.54 ± 0.13	0.026
$W_{AER}N$ [kJ/kg]	3.93 ± 0.46	4.16 ± 0.28	3.74 ± 0.56	3.74 ± 0.56	3.78 ± 0.70	< 0.001
$W_{TOT}N$ [kJ/kg]	5.23 ± 0.54	5.54 ± 0.39	4.88 ± 0.67	5.01 ± 0.84	2.82 ± 0.55	< 0.001
τ_1 [s]	16.65 ± 7.03	17.85 ± 2.44	16.19 ± 3.69	14.53 ± 4.84	24.08 ± 7.34	< 0.001
W_{AER} [%]	75.60 ± 3.87	75.28 ± 3.87	76.75 ± 4.40	75.24 ± 3.31	68.92 ± 3.47	< 0.001

G1 = group 1; G2 = group 2; G3 = group 3; W_{PCR} = anaerobic alactic energy contribution; W_{BLC} = anaerobic lactic energy contribution; W_{AER} = aerobic energy contribution; W_{TOT} = total energy contribution; $W_{PCR}N$ = normalized anaerobic alactic energy contribution; $W_{BLC}N$ = normalized anaerobic lactic energy contribution; $W_{AER}N$ = normalized aerobic energy contribution; $W_{TOT}N$ = normalized total energy contribution; τ_1 = time constant

in kayaking was significantly greater than that in running. W_{TOT} in kayaking, canoeing, running, and cycling were significantly greater than that in arm cranking. W_{TOT} in kayaking and canoeing were significantly greater than that in running. $W_{PCR}N$ in kayaking, canoeing, running, and cycling were significantly greater than that in arm cranking. $W_{PCR}N$ in kayaking and canoeing were significantly greater than those in cycling. $W_{AER}N$ in kayaking, canoeing, running, and cycling were significantly greater than that in arm cranking. $W_{TOT}N$ in kayaking, canoeing, running, and cycling were significantly greater than that in arm cranking. τ_1 in kayaking, running, and cycling were significantly smaller than that in arm cranking. W_{AER} % in kayaking, canoeing, running, and cycling were significantly greater than that in arm cranking. τ_1 had a significant and negative correlation with W_{AER}% (r = -0.298, p = 0.014) (Figure 6-1). The time course of relative VO_2 in all the studied movements was demonstrated in Figure 6-2.

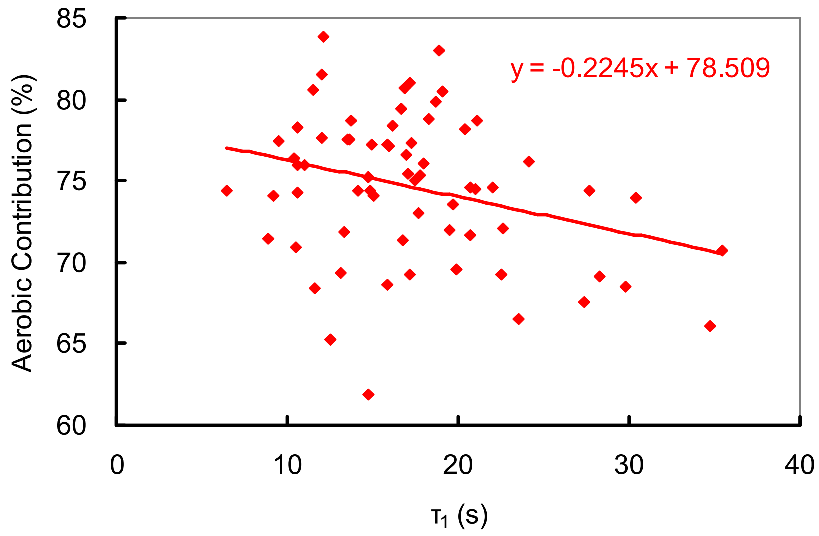

Figure 6-1: Relationship between W_{AER} % and time constant (τ_1) (r = -0.298, p = 0.014)), raw data see Appendix 13

6.4 Discussion

The purpose of this study was to examine whether movement patterns could influence on W_{AER} % in exercises with maximal effort. Accordingly, three groups of participants were recruited to perform five movement patterns (kayaking, canoeing, running, cycling, and arm cranking) with maximal effort. Among the five movement patterns, kayaking, canoeing, and arm cranking were upper-body dominant, whereas running and cycling were lower-body dominant. Among the three groups, G1 and G2 were highly trained athletes, whereas G3 were amateur-level athletes.

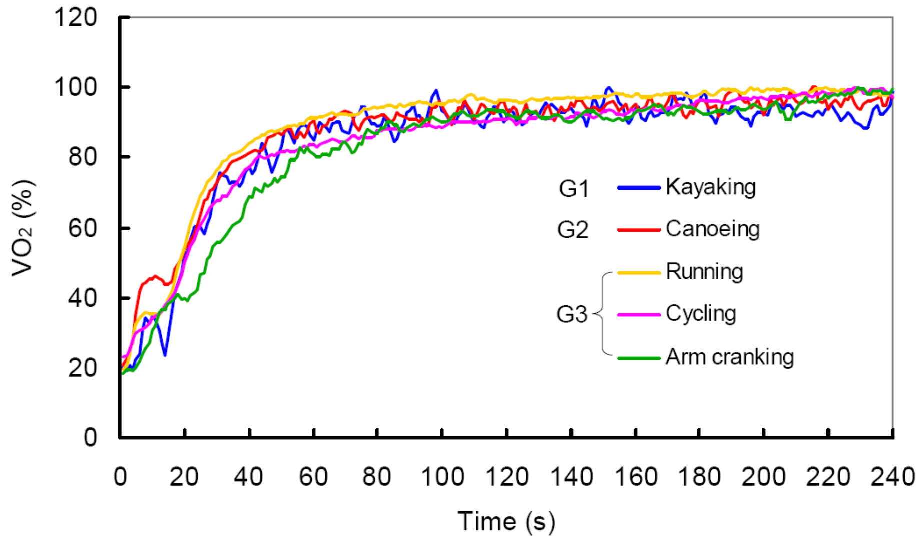

Figure 6-2: Averaged VO_2 kinetics of the five studied maximal exercises (G1 = group 1; G2 = group 2; G3 = group 3), raw data see Appendix 14

For G3, arm cranking produced significantly lower W_{PCR}, W_{AER}, and W_{TOT}, W_{PCR} N, W_{AER}N, W_{TOT}N, but not W_{BLC}, than running and cycling (Table 6-2), which was caused by slower VO_2 kinetics and a lower volume of involved muscle mass. The participants in G3 were from running, cycling, and triathlon, in which most of the training is focused on the lower body. However, their upper body was relatively untrained in G3. Although our subjects did not undergo muscle biopsy, it was well documented that the percentage of slow twitch fiber was significantly lower in the upper-body muscles compared to those of the lower-body muscles in upper-body untrained subjects (JOHNSON, 1973; SALTIN ET AL., 1977), especially in lower-body endurance trained athletes (TESCH & KARLSSON, 1985). Therefore, it was speculated that the participants in G3 were characterized by a high percentage of slow twitch fiber in lower-body muscles, and a high percentage of fast twitch fiber in upper-body muscles. Because of a higher level of fast twitch fiber, the fast component time constant of VO_2 kinetics was longer in upper-body exercises compared to lower-body exercises in upper-body untrained subjects (JENSEN-URSTAD ET AL., 1993; KOGA ET AL., 1996; KOPPO ET AL., 2002). The findings in this study are in line with these reports with τ_1 significantly longer in arm cranking than in running and cycling (Table 6-2, Figure 6-2). The slow VO_2 kinetics in arm cranking at the start of exercise led to higher demand of energy supply from the anaerobic metabolic pathway

(JENSEN-URSTAD ET AL., 1993). Additionally, because the involvement of muscles in arm cranking is much less than in running and cycling (BENEKE, 2003b), as well as the dependence of anaerobic alactic capacity on muscle mass (GREENHAFF ET AL., 2004), a significantly lower supply of W_{PCR} in arm cranking was also expected. In summary, a significantly lower W_{PCR} and W_{AER} led to a significantly lower W_{TOT} (Table 6-2). However, it was the significantly slower VO_2 kinetics that resulted in a significantly lower W_{AER} % in arm cranking, which was probably caused by the high portion of fast twitch fiber in the upper-body muscles of the participants in G3.

Since it was found that the VO_2 kinetics could be improved with training (CERRETELLI ET AL., 1979), two upper-body highly trained groups (G1 and G2) were also recruited in this study. The findings indicated the training level of upper body did have an influence on VO_2 kinetics, energy contributions, and W_{AER} %. As shown in Table 6-1, participants in G1 and G2 were taller and they had a heavier body mass as well as a higher level of peak VO_2, even though the peak VO_2 of G1 and G2 was from kayaking or canoeing, as compared to that from running for G3. These physical and physiological advantages of G1 and G2 led them to a significantly higher level of energy contributions, except W_{BLC} (Table 6-2). Notably, the highly trained G1 and G2 had similar VO_2 kinetics as G3 in running and cycling, which were significantly faster than G3 in arm cranking (Figure 6-2). The findings of VO_2 kinetics here were in agreement with others. Cerretilli et al. (1979) demonstrated that kayakers had faster VO_2 kinetics than sedentary subjects, and that the faster oxygen kinetics were accompanied with a lower level of blood lactate (CERRETELLI ET AL., 1979). Findings from rowing indicated that elite rowers had faster VO_2 kinetics compared to club level rowers (INGHAM ET AL., 2007). The same findings were also reported in cycling (KOPPO ET AL., 2004). The faster oxygen kinetics of trained muscles, as mentioned above, probably resulted from a higher portion of slow twitch fiber (BARSTOW ET AL., 1996; PRINGLE ET AL., 2003). Compared to a higher portion of fast twitch fiber in upper-body muscles in upper-body untrained subjects (JOHNSON, 1973; SALTIN ET AL., 1977), heavily trained kayakers were reported to be of a higher portion of slow twitch fiber in the upper-body muscles (TESCH & KARLSSON, 1985). Consequently, probably resulting from a higher portion of slow twitch fiber in the upper-body muscles, G1 and G2 were characterized by faster VO_2 kinetics than G3 showed in arm cranking, which might be the primary cause of a higher W_{AER} % in G1 and G2 than in G3 in arm cranking.

Taking the studied five movement patterns as a whole, it was postulated that W_{AER}% would be similar in maximal exercises involving muscles of comparable training level (e.g., upper-body muscles in kayakers and canoeists, and lower-body muscles in runners and cyclists) or comparable muscle fiber composition, regardless of movement patterns. In other words, there might be a positive relationship between W_{AER} % and the percentage of slow twitch fiber in the involved muscles during a given duration of maximal exertion, by means of the time constant of VO_2 kinetics (τ_1). This could explain, at least partly, the variation of W_{AER} % among different investigations.

6.5 Conclusion

W_{AER} % during maximal exercise seemed to be independent of movement patterns, given similar VO_2 kinetics during the maximal exertion, as well as certain duration of maximal exertion (e.g., 4 min as in this study). Involved muscle volume had an influence on absolute energy contribution, but not W_{AER} %. It was primarily the VO_2 kinetics, together with the duration, that determined the W_{AER} % in maximal exercises. An exponential relationship between W_{AER}% and duration in maximal exercises was found previously by summarizing the literature on a variety of movement patterns (GASTIN, 2001) (also see Chapter 2); this study provided further support for that finding by excluding the influence from movement patterns.

7 Maximal Lactate Steady State in Kayaking

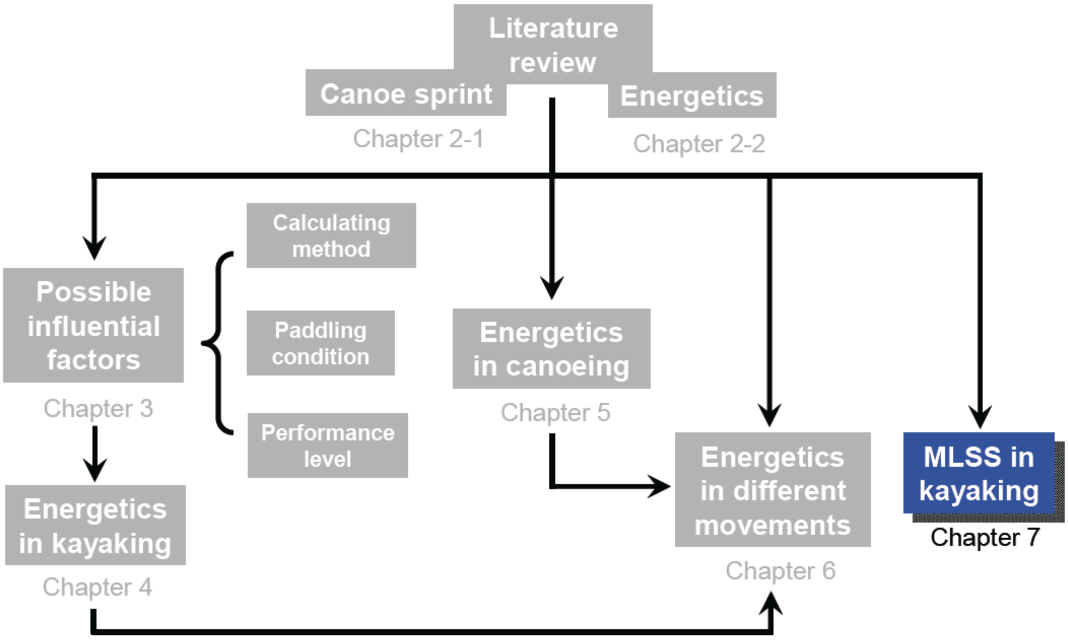

Illustration of the research design - Chapter 7

7.1 Introduction

The response of blood lactate concentration to exercise is the result of complex interrelationships between the formation, distribution, and utilization of lactate in various tissues and compartments (MADER & HECK, 1986). The oxygen consumption during exercise above which aerobic energy production is supplemented by anaerobic mechanisms, and which results in a significant increase in lactate, is termed the anaerobic threshold (WASSERMAN, 1984). MLSS corresponds to the highest workload that can be maintained over time without continuous blood lactate accumulation (BENEKE, 1995; HECK ET AL., 1985). Direct assessment of MLSS requires multiple submaximal constant workload tests across several days, which makes it a time-consuming process (HECK, 1990b). Therefore, investigators tried to find an alternative for the traditional approach (BILLAT ET AL., 1994; HECK ET AL., 1985; MADER ET AL., 1976). One approach was to estimate an anaerobic threshold with a fixed lactate value of 4 mM (LT4), originally defined by Mader et al. (1976). The approach was used in the training of kayaking in Germany (CAPOUSEK, 2009; KAHL, 2005).

In the last decades, MLSS has been extensively studied in different types of locomotion, such as running (HECK ET AL., 1985), cycling (BENEKE & VON DUVILLARD, 1996), rowing (BENEKE & VON DUVILLARD, 1996), swimming (DEKERLE ET AL., 2005), and speed skating (BENEKE & VON DUVILLARD, 1996). However, a range of 2–7 mM has been found for blood lactate values at MLSS among different types of locomotion; for example, 3.1 mM in rowing, 5.4 mM in cycling, and 6.6 mM in speed skating (BENEKE & VON DUVILLARD, 1996) The differences could be associated with the different sport-specific muscles (BENEKE & VON DUVILLARD, 1996). Kayaking is a sport activity characterized by great demands on upper-body performance (TESCH, 1983). The use of LT4 was originally developed in running, because the average MLSS was found to be 4.02 mM (range 3.05 to 5.52 mM) (MADER ET AL., 1976). However, the locomotion of running involves mainly lower extremity muscles. Upper-body and lower-body muscles were characterized with different muscle fiber composition (JOHNSON, 1973), which could result in differences in lactate production and in VO_2 kinetics

(HECK ET AL., 1994; KOPPO ET AL., 2002). Consequently, using LT4 in kayaking might lead to significant errors. However, no study had investigated MLSS in kayaking. Therefore, the purpose of the study is to measure the MLSS and workload at MLSS in kayaking. It was hypothesized that MLSS in kayaking would be different from 4mM and the corresponding workload at MLSS would be different from the calculated workload using a fixed blood lactate value of 4 mM.

7.2 Methods

7.2.1 Subjects

Eight junior kayakers (four males and four females, age 15.1 ± 1.2 yrs; height 179.9 ± 7.3 cm; body mass 72.3 ± 4.9 kg) volunteered to participate in this study. The participants had an average of 2 year’s (1.5-2.4 yrs) training experience in kayaking, with a weekly training volume of approximate 14 h. The test was performed in January. No subject had received pharmacological or dietetic treatment in the prior six months. The detailed procedure was informed to the participants and their parents. The participants and their parents signed consent forms before the testing. The study was conducted according to the corresponding ethics requirement.

7.2.2 Procedures

Subjects participated in an incremental workload test and 2–5 submaximal constant workload tests at similar times of the day on separate days. The tests were performed on a kayaking ergometer (Dansprint, I Bergmann A/S, Hvidovre, Denmark), with a fan resistance factor of 3. Strenuous activity was not allowed 24 h before each test, and a break of at least 24 h was given between the two trials. No food, but drink, was permitted two hours before the test. A typical diet high in carbohydrates was adhered to by the subjects before the tests.

The initial load for the incremental test was 55–85 watts according to individual performance as found during training. The test consisted of 4 to 6 steps of 5 min, with an incremental step of 15 watts and a break of 1 min after each step for blood sampling (BISHOP, 2000). The incremental test was conducted until that the participants could not paddle with the designed workload. Spoken encouragement was given during the incremental test to ensure a high motivation.

All constant workload tests lasted 30 min, with a break of 30 s after each 5 min step for blood sampling. The first constant test was performed with a workload corresponding to individual LT4, which was linear-interpolated from the incremental workload test. The workload in the following trials was 5–15 watts more or less, depending on the lactate change in the last trial. The maximal workload with an increase of blood lactate less than 1 mM during the last 20 min was determined as the MLSS workload, whereas the average blood lactate value during the last 20 min under this workload was determined as the blood lactate value at MLSS (BENEKE, 1995; HECK ET AL., 1985).

From each subject, 20 μL blood was taken from the earlobe before the test and after each step in the incremental test, as well as before the test and after each 5 min in the constant workload test. The blood samples were analyzed with a lactate analyzer (Biosen S_line, EKF Diagnostic, Barleben, Germany).

7.2.3 Statistical Analysis

Two subjects were unable to complete 30 min constant test with a workload above MLSS. Therefore, six subjects had the blood lactate data at workload above MLSS. The workload at MLSS was compared to the workload above MLSS using a two-tailed paired t-test ($N = 6$). Blood lactate values between workload at and above MLSS at different 0-30 min time points were compared using a two-tailed paired t-test ($N = 6$). The relationship between the blood lactate value at MLSS and the workload at MLSS was examined using Pearson correlation ($N = 8$). The measured workload at MLSS and the calculated workload using a fixed lactate value of 5.4 mM, 5.0 mM, or 4 mM were compared using repeated measure ANOVA, followed by pair-wise comparisons ($N = 8$). P values were set at 0.05 for statistical significance. The Holm’s step-down procedure was used to adjust the type-I error rate of each pair-wise comparison to keep the overall type-I error rate of ANOVA at 0.05. Statistical analysis was performed using IBM SPSS Statistics 19 (SPSS Statistics 19, IBM Corporation, New York, USA).

7.3 Results

The blood lactate value at MLSS was 5.4 ± 0.7 mM in kayaking. The workload at MLSS was 112 ± 22 watts, whereas the workload above MLSS was 120 ± 21 watts ($p = 0.024$, Figure 7-1). The blood lactate level at workload above MLSS was greater than that at the MLSS workload at 10-30 min time points ($p < 0.05$, Figure 7-1). The blood lactate value at MLSS was not significantly correlated with workload at MLSS ($p = 0.55$, $r = -0.25$, Figure 7-2). ANOVA showed significant differences among measured workloads at MLSS and calculated workload using a fixed lactate level ($p = 0.003$). Pair-wise comparisons showed that the measured MLSS workloads were significantly greater than the calculated workload using a lactate value of 4 mM (104 ± 18 watts, $p = 0.016$). However, the measured workload at MLSS was not significantly different from the calculated workload using a lactate value of 5.4 mM (115 ± 19 watts, $p = 0.16$) or 5.0 mM (113 ± 19 watts, $p = 0.78$). In addition, the calculated workloads using a lactate value of 5.4 mM and 5.0 mM were greater than the calculated workloads using a lactate value of 4.0 mM ($p < 0.001$) (Figure 7-3).

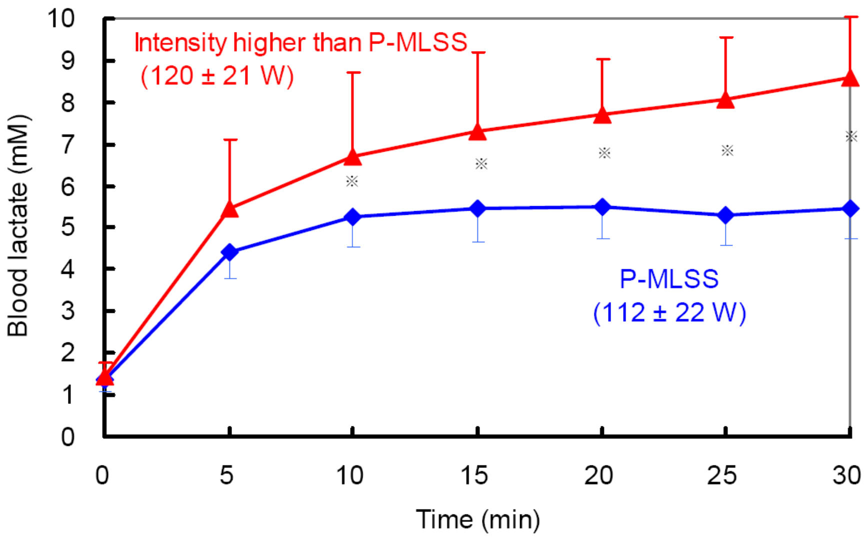

Figure 7-1: Blood lactate concentration at and above MLSS workload (P-MLSS) (N = 8 for MLSS workload; N = 6 for workload higher than P-MLSS); ※ significant correlation between blood lactate at and above MLSS workload (P ＜ 0.05), raw data see Appendix 15

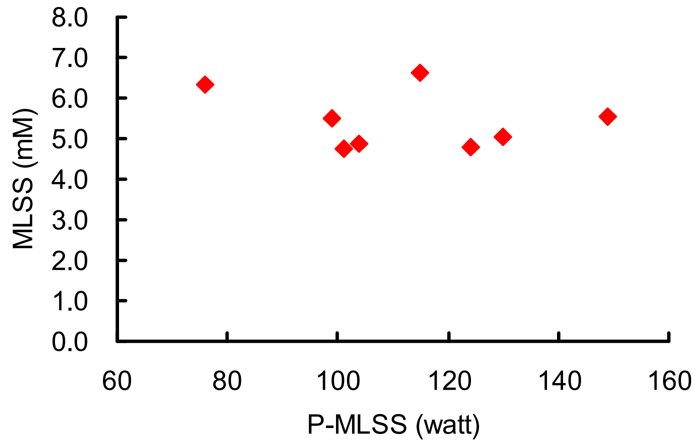

Figure 7-2: Correlation between MLSS and MLSS workload (N = 8), raw data see Appendix 16

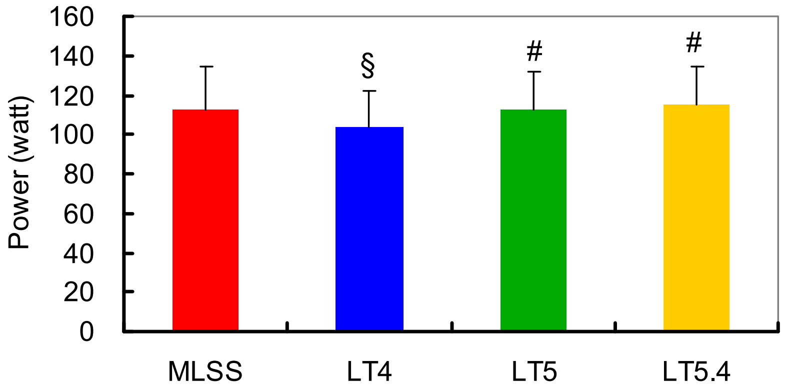

Figure 7-3: Workload at MLSS and different lactate threshold; LT4, LT5, LT5.4 = lactate threshold with fixed value of 4, 5, and 5.4); § = significant from MLSS ($P < 0.05$); # = significant from LT4 ($P < 0.05$) (N = 8), raw data see Appendix 17

7.4 Discussion

The primary finding in this study was a blood lactate value of 5.4 mM at MLSS in kayaking. The findings could expand the knowledge of MLSS in different locomotion. A review of literature indicated that the blood lactate values at MLSS were on average 3.05 mM (range 2.7 mM to 3.7 mM) in rowing (BENEKE ET AL., 2001), 4.92 mM (range 3.2 mM to 6.7 mM) in cycling (BENEKE ET AL., 2009), 3.25 mM (range 3.2 mM to 3.3 mM) in swimming (DEKERLE ET AL., 2005), 6.6 mM in speed skating (BENEKE & VON DUVILLARD, 1996), 3.4 mM (range 2.1 mM to 4.6 mM) in running (HECK ET AL., 1985), and 5.83 mM in arm cranking (HECK ET AL., 1994). As concluded by Beneke et al. (2001; 1996), MLSS was associated with the motor pattern of locomotion, but not likely with gender (BENEKE ET AL., 2009), age (BENEKE ET AL., 2009; BENEKE ET AL., 1996), or performance (BENEKE ET AL., 2000). Therefore, even though the subjects in this study were junior kayakers of both genders with lower performance, the findings of MLSS from them could still represent the motor pattern of kayaking.

MLSS represents the highest point of equilibrium between the production and removal of lactate. If the rate of lactate removal is higher than the rate of production, lactate will accumulate, and the corresponding workload is above the MLSS workload (BILLAT ET AL., 2003; HECK ET AL., 1985). Previous investigators showed that the production and removal of lactate depended on exercise intensity and involved muscle mass (BENEKE ET AL., 2001), which is related to the consumption of lactate according to the lactate shuttle theory (BROOKS, 1991). In terms of different locomotion, the workloads at MLSS were found to be 70–80 % of the corresponding maximal workloads, regardless of types of locomotion (BENEKE & VON DUVILLARD, 1996). Similar exercise intensity (82 %) was also found in this study. However, the relatively less-active muscle mass involved in kayaking allowed a relatively greater inactive or moderate-exercise muscle mass, which could play a role as lactate consumer (GLADDEN, 2000). Accordingly, the locomotion of kayaking could provide a higher level of lactate removal capacity compared to other locomotion types, such as rowing and running. Therefore, a relatively high level of lactate equilibrium (5.4 mM) becomes possible. Additionally, an even higher MLSS in arm cranking (5.83 mM) also makes sense because even less muscle mass is involved in this locomotion. However, the highest MLSS, which is found in speed skating (6.6 mM), is not clearly understood (BENEKE & VON DUVILLARD, 1996), although evidence of restricted muscle blood flow was found during speed skating (FOSTER ET AL., 1999).

Kayaking is primarily an upper-body exercise (UBE). The specific physiological responses of this kind of exercise should also be considered when MLSS is concerned (PENDERGAST, 1989; PENDERGAST ET AL., 1979). Upper-body muscles are characterized with a higher percentage of fast twitch fiber (JOHNSON, 1973), which might result in more lactate production and a longer fast component time constant of VO_2 kinetics than lower-body muscles have during exercises (HECK ET AL., 1994; KOPPO ET AL., 2002). Hence, with regard to MLSS, the physiological response caused by a higher fast twitch fiber in the upper-body muscles might have an influence on the lactate production in kayaking.

Originally, MLSS in running provided solid support for a fixed lactate value of 4 mM in anaerobic threshold (HECK ET AL., 1985; MADER ET AL., 1976). However, attention should be paid when extending these findings from running to other locomotion types, such as kayaking. The current study showed that the MLSS in kayaking was 5.4 mM rather than 4mM. The workload interpolated according to 4 mM was lower than the actual workload at MLSS in kayaking (Figure 8-3). When the training intensity was designed for different sports based on LT4, an intensity of extensive endurance ((i.e. 2-4 mM) in one sport with a higher MLSS (i.e., 5.4 mM as in kayaking) might be an intensity of intensive endurance in the other sport with a lower MLSS (i.e., 3.05 mM as in rowing) (CAPOUSEK, 2009; HARTMANN ET AL., 1989). Actually, the elite kayakers spent 85–88 % of their water training with an intensity of 2–4 mM (CAPOUSEK, 2009; ENGLERT & KIESSLER, 2009), whereas the rowers spent 70–90 % of their water training with an intensity of ＜ 2 mM, rather than 2–4 mM, where the percentage was only 5–22 % (HARTMANN ET AL., 1989). Therefore, it is recommended that a fixed lactate value of 5 mM, instead of 4 mM, should be utilized in diagnostics in kayaking, and that dividing the training zones of intensity should be based on LT5.

The incremental workload test utilized in this study was with 5 min duration for each step, and with a 1 min interval break. However, the protocol of the incremental test did have an influence on the threshold workload with a fixed lactate value. It has been found that the workload at LT4 decreased with a longer duration (3 min vs. 5 min vs. 7 min) of each step, and a shorter interruption between each two steps (1.5 min vs. 1.0 min vs. 0.5 min) in the incremental test (HECK ET AL., 1985). These findings were also supported by cases of rowing and kayaking in training practice. An increment duration of 8 min was preferred instead of 3 min in rowing, because the workload at LT4 from the 3 min incremental test was found to be too high for constant submaximal rowing, an 8 min incremental test, but still with LT4, was preferred in rowing (HARTMANN ET AL., 1988a). Comparatively, an interruption of approximately 10 min was preferred instead of 1 min in kayaking, because the workload at LT4 from such incremental test with 1 min interruption was found to be too low for constant submaximal kayaking (ENGLERT & KIESSLER, 2009). Therefore, when a fixed blood lactate value was utilized to calculate the workload at MLSS, the protocol of the incremental test should be taken into account.

7.5 Conclusion

In conclusion, the blood lactate value of MLSS was found to be 5.4 mM in kayaking, which could expand the knowledge of MLSS in different types of locomotion. The MLSS in kayaking might be attributed to the involved muscle mass in this locomotion, which could result in a certain level of lactate removal, and could allow a certain level of equilibrium between lactate production and removal. LT5, instead of LT4, was recommended for diagnostics in kayaking, given an incremental test as used in this study.

8 General Summary

This study reviewed first the development of race result in canoe sprint during the past decades. The race results of MK1-1000 and WK1-500 have increased 32.5 % and 42.1 %, respectively, a corresponding 5.0 % and 6.5 % increase in each decade. The development of race results in canoe sprint during the past decades resulted from the contributions of various aspects. The recruitment of taller and stronger athletes improved the physiological capacity of paddlers. Direct investigation on energy contribution in canoe sprint enhanced the emphasis on aerobic capacity and aerobic endurance training. Advancement of equipment design improved the efficiency of paddling. Physiological and biomechanical diagnostics in canoe sprint led to a more scientific way of training. Additionally, other aspects might also have contributed to the development of race results during the past decades. For example, the establishment of national team after World War II provided the possibility of systematic training, and the use of drugs in the last century accelerated the development of race results in that period.

Recent investigations on energetics in high-intensity exercises demonstrated an underestimate of W_{AER} % in the table provided by some textbooks since the 1960s. An exponential correlation between W_{AER} % and the duration of high-intensity exercises was concluded from summarizing most of the relevant reports, including reports with different methods of energy calculation. However, when reports with the MAOD and Pcr-La-O_2 methods were summarized separately, a greater overestimate of W_{AER} % from MAOD was found compared to those from Pcr-La-O_2, which was in line with the critical reports on MAOD. Because of the lack of investigation of the validity of the comparisons between MAOD and Pcr-La-O_2, it is still not clear which method can generate more accurate results and which method is more reliable.

With regard to kayaking, a range of variation in W_{AER} % was observed. Many factors might contribute to the variation of W_{AER} % in kayaking. Therefore, the methods utilized to calculate the energy contributions, different paddling conditions, and the level of performance were investigated in kayaking. The findings indicated that the method utilized to calculate the energy contributions in kayaking, rather than paddling condition and performance level of paddlers, might be the possible factor associated with W_{AER} %. Some other possible factors associated with W_{AER} % still need to be further investigated in the future.

After verifying the dependence of W_{AER} % on the method of energy calculation, but not on paddling condition and performance level of paddlers, energy contributions of kayaking were investigated for the three racing distances on a kayak ergometer with junior paddlers. Energetic profiles in kayaking varied with paddling distances. At 500 m and 1000 m the aerobic system was dominant (with W_{AER} % of 57.8 % and 76.2 %), whereas at 200 m the anaerobic system was dominant (with W_{AER} % of 31.1-32.4 %). Muscular volume seemed to have an influence on absolute energy productions. The anaerobic alactic system determined the performance during the first 5 to 10 s. The anaerobic lactic system probably played a dominant role during the period from the 5^{th}-10^{th} s to 30^{th}-40^{th} s. The aerobic system could dominate the energy contribution after 30–40 s. This energetic profile in kayaking could provide physiological support for developing the training philosophy in these three distances. Additionally, the method introduced by Beneke et al. seemed to be a valid method to calculate the energy contributions in maximal kayaking.

Energy contributions in canoeing were similar to those in kayaking. The relative energy contributions on open water canoeing were 75.3 ± 2.8 % of aerobic, 11.5 ± 1.9 % of anaerobic lactic, and 13.2 ± 1.9 % of anaerobic alactic at maximal speed of simulated 1000 m. Further, the C of canoeing seemed also to be similar to the reported findings in kayaking, with a function of $y = 0.0242 * x^{2.1225}$. Training programs could be designed similarly for kayaking and canoeing with regard to energetic profile.

In order to extend the findings on energetics in canoe sprint to other exercises, energy contributions in kayaking, canoeing, running, cycling, as well as arm cranking were compared with the same duration. Results indicated that W_{AER} % during maximal exercises with the same duration seemed to be independent of movement patterns, given similar VO_2 kinetics during the maximal exertion. The exponential relationship between W_{AER} % and duration in maximal exercises could be supported by excluding the influence from movement patterns.

Additionally, MLSS in kayaking was investigated. The blood lactate value of MLSS was found to be 5.4 mM in kayaking, which could expand the knowledge of MLSS in different locomotion. The MLSS in kayaking might be attributed to the involved muscle mass in this locomotion, which could result in a certain level of lactate removal, and allow a certain level of equilibrium between lactate production and removal. LT5, instead of LT4, was recommended for diagnostics in kayaking, given an incremental test as used in this study.

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Appendix 1: Race Results for MK1-1000 and WK1-500

MK1-1000							
Year	Time	Year	Time	Year	Time	Year	Time
1948	04:33.2	1964	03:57.1	1980	03:48.8	1996	
1949		1965		1981	03:45.1	1997	
1950	04:18.1	1966	03:59.3	1982	03:55.5	1998	
1951		1967	03:54.7	1983	04:00.6	1999	
1952	04:07.9	1968	04:02.6	1984	03:45.7	2000	03:33.3
1953		1969	04:02.5	1985	03:40.2	2001	03:34.8
1954	04:23.5	1970	03:41.1	1986	03:37.6	2002	03:27.6
1955		1971	03:46.6	1987	03:53.5	2003	03:28.9
1956	04:12.8	1972	03:48.1	1988	03:55.3	2004	03:25.9
1957		1973	03:51.7	1989	03:38.9	2005	03:29.2
1958	03:51.4	1974	04:03.2	1990	03:33.2	2006	03:39.4
1959		1975	03:43.5	1991	03:35.2	2007	03:40.1
1960	03:53.0	1976	03:48.2	1992	03:37.3	2008	03:26.3
1961		1977	03:53.9	1993	03:42.5	2009	03:29.4
1962		1978	03:49.4	1994		2010	03:29.5
1963	03:56.3	1979	03:58.6	1995		2011	03:36.2
WK1-500							
Year	Time	Year	Time	Year	Time	Year	Time
1948	02:31.9	1964	02:12.9	1980	01:58.0	1996	01:47.7
1949		1965		1981		1997	
1950		1966		1982		1998	
1951		1967		1983		1999	
1952	02:18.4	1968	02:11.1	1984	01:58.7	2000	02:13.8
1953		1969		1985		2001	01:53.6
1954		1970		1986		2002	01:52.1
1955		1971		1987		2003	01:49.0
1956	02:18.9	1972	02:03.2	1988	01:55.2	2004	01:47.7
1957		1973		1989		2005	01:50.4
1958	02:02.1	1974		1990		2006	01:52.3
1959		1975		1991		2007	01:48.7
1960	02:08.1	1976	02:01.1	1992	01:51.6	2008	01:50.7
1961		1977		1993		2009	01:51.5
1962		1978		1994		2010	01:50.5
1963		1979		1995		2011	01:47.1

Appendix 2: Height and Body Mass of Male Paddlers in Several Olympic Games

		1964	1972	1976	1980	2000	2012
Height	[m]	1.79	1.77	1.80	1.82	1.84	1.85
Weight	[kg]	76.0	75.0	78.0	80.8	85.2	88.0

(ACKLAND ET AL., 2003;COX, 1992; LI, 2012; SHEPHARD, 1987)

Appendix 3: Body Mass and VO_{2peak} from Several National Paddlers

Authors	Year	Country	Mass [kg]	VO_{2max}-Kayak Ergometer [l/min]
FRY & MORTON	1991	AUS	81.1	4.78
BISHOP & PALMER	2003	AUS	80.4	4.07
VAN SOMEREN ET AL.	2003	GBR	84.5	4.45
KROFF	2005	RSA	78.6	4.4
BONETTI ET AL.	2006	NZL	81.2	4
FORBES & CHILIBECK	2007	CAN	76.3	3.64
GARCIA-PALLARES ET AL.	2010	ESP	86.2	5.59
BISHOP	2000	AUS	70.4	3.15
FORBES & CHILIBECK	2007	CAN	61.6	2.86

Appendix 4: Yearly Training Volumes in Hour from Literatures

Year	77/78	78/79	79/80	80s	89/90	94/95	03/04	04/05	05/06	06/07	07/08
Total	1255	1360	1440	1100	900	630	787.5	675	585	765	801
Specific	540	780	850	/	540	360	459	405	405	549	544.5

(77/78, 78/79, 79/80 (LENZ, 1994); 80 s (ISSURIN, 2008); 89/90, 94/95 (KAHL, 1997); 03/04 (FISCHER, 2006); 04/05 (CAPOUSEK, 2009); 05/06, 06/07, 07/08 (ENGLERT & KIESSLER, 2009))

Appendix 5: W_{AER} % of Maximal Exercises in Literatures

Literature	Sport Event	Duration	W_{AER}%	Method
(BANGSBO ET AL., 1993)	run (treadmill)	4.05	83.1	MAOD
(BANGSBO ET AL., 1993)	run (treadmill)	6.00	83.9	MAOD
(BISHOP ET AL., 2001)	kayak (ergometer)	2.00	65.7	MAOD
(BISHOP ET AL., 2001)	kayak (ergometer)	2.00	65.8	MAOD
(BISHOP ET AL., 2001)	kayak (ergometer)	2.00	68.1	MAOD
(GASTIN ET AL., 1995)	cycle (ergometer)	1.50	57.0	MAOD
(GASTIN ET AL., 1995)	cycle (ergometer)	3.47	74.0	MAOD
(GASTIN, P. & LAWSON, D., 1994)	cycle (ergometer)	0.75	38.0	MAOD
(GASTIN, P. & LAWSON, D., 1994)	cycle (ergometer)	1.00	45.0	MAOD
(GASTIN ET AL., 1995)	cycle (ergometer)	1.03	51.0	MAOD
(GASTIN, P. & LAWSON, D., 1994)	cycle (ergometer)	1.50	58.0	MAOD
(GASTIN ET AL., 1995)	cycle (ergometer)	1.57	59.0	MAOD
(GASTIN ET AL., 1995)	cycle (ergometer)	3.10	76.0	MAOD
(WITHERS ET AL., 1993)	cycle (ergometer)	0.75	40.0	MAOD
(WITHERS ET AL., 1993)	cycle (ergometer)	1.00	47.0	MAOD
(WITHERS ET AL., 1993)	cycle (ergometer)	1.25	54.0	MAOD
(WITHERS ET AL., 1993)	cycle (ergometer)	1.50	60.0	MAOD
(BANGSBO ET AL., 1993)	run (treadmill)	3.42	77.9	MAOD
(FAINA ET AL., 1997)	run (field)	3.75	83.6	MAOD
(FRIEDMANN ET AL., 2001)	run (treadmill)	2.23	59.8	MAOD
(FRIEDMANN ET AL., 2001)	run (treadmill)	2.60	62.9	MAOD
(NUMMELA & RUSKO, 1995)	run (treadmill)	0.82	45.6	MAOD
(GASTIN, P.B. & LAWSON, D.L., 1994)	cycle (ergometer)	1.50	58.0	MAOD
(BISHOP ET AL., 2002)	kayak (ergometer)	2.00	62.3	MAOD
(BISHOP ET AL., 2002)	kayak (ergometer)	2.00	60.9	MAOD
(DUFFIELD ET AL., 2004)	run (field)	0.22	25.0	MAOD
(DUFFIELD ET AL., 2005b)	run (field)	5.30	86.0	MAOD
(DUFFIELD ET AL., 2004)	run (field)	0.45	33.2	MAOD
(DUFFIELD ET AL., 2005b)	run (field)	11.60	94.0	MAOD
(DUFFIELD ET AL., 2005a)	run (field)	1.00	44.5	MAOD
(DUFFIELD ET AL., 2005a)	run (field)	2.50	70.1	MAOD
(MINAHAN ET AL., 2007)	cycle (ergometer)	2.78	69.3	MAOD
(PRIPSTEIN ET AL., 1999)	row (ergometer)	7.50	87.7	MAOD
(AISBETT ET AL., 2003)	cycle (ergometer)	6.00	87.9	MAOD
(AISBETT ET AL., 2003)	cycle (ergometer)	6.00	88.6	MAOD
(AISBETT ET AL., 2003)	cycle (ergometer)	6.00	88.0	MAOD
(BELL ET AL., 2001)	cycle (field)	1.85	61.5	MAOD
(BISHOP, 2000)	kayak (ergometer)	2.00	70.3	MAOD
(SPENCER & GASTIN, 2001)	run (treadmill)	0.37	29.0	MAOD

(SPENCER & GASTIN, 2001)	run (treadmill)	0.82	43.0	MAOD
(SPENCER & GASTIN, 2001)	run (treadmill)	1.88	66.0	MAOD
(SPENCER & GASTIN, 2001)	run (treadmill)	3.92	84.0	MAOD
(RAVIER ET AL., 2006)	run (treadmill)	2.20	61.7	MAOD
Own data	kayak (ergometer)	0.67	36.1	MAOD
Own data	kayak (ergometer)	4.00	60.9	MAOD
(FAINA ET AL., 1997)	arm crank (ergometer)	5.93	88.5	MAOD
(CALBET ET AL., 1997)	cycle (ergometer)	0.50	22.9	MAOD
(CALBET ET AL., 1997)	cycle (ergometer)	0.75	30.9	MAOD
(CALBET ET AL., 1997)	cycle (ergometer)	2.50	58.5	MAOD
(DUFFIELD ET AL., 2004)	run (field)	0.19	20.6	MAOD
(DUFFIELD ET AL., 2005b)	run (field)	4.40	77.0	MAOD
(DUFFIELD ET AL., 2004)	run (field)	0.40	28.4	MAOD
(DUFFIELD ET AL., 2005b)	run (field)	9.60	86.0	MAOD
(DUFFIELD ET AL., 2005a)	run (field)	0.90	41.3	MAOD
(NUMMELA & RUSKO, 1995)	run (treadmill)	0.83	37.1	MAOD
(DUFFIELD ET AL., 2005a)	run (field)	2.10	60.3	MAOD
(MINAHAN ET AL., 2007)	cycle (ergometer)	2.92	70.0	MAOD
(WITHERS ET AL., 1991)	cycle (ergometer)	0.50	28.0	MAOD
(WITHERS ET AL., 1991)	cycle (ergometer)	1.00	49.0	MAOD
(WITHERS ET AL., 1991)	cycle (ergometer)	1.50	61.0	MAOD
(MEDBO & TABATA, 1989)	cycle (ergometer)	0.60	30.0	MAOD
(MEDBO & TABATA, 1989)	cycle (ergometer)	1.25	47.0	MAOD
(MEDBO & TABATA, 1989)	cycle (ergometer)	2.60	65.0	MAOD
(BISHOP ET AL., 2003)	kayak (ergometer)	2.00	59.1	MAOD
(BISHOP ET AL., 2003)	kayak (ergometer)	2.00	60.3	MAOD
(CRAIG ET AL., 1995)	cycle (ergometer)	1.17	55.3	MAOD
(CRAIG ET AL., 1995)	cycle (ergometer)	1.17	50.2	MAOD
(GARDNER ET AL., 2003)	cycle (ergometer)	1.88	61.8	MAOD
(BANGSBO ET AL., 1993)	run (treadmill)	3.01	77.9	MAOD
(REIS ET AL., 2010)	swim (crawl)	1.41	72.7	MAOD
(REIS ET AL., 2010)	Swim (crawl)	2.95	85.7	MAOD
(RAVIER ET AL., 2006)	run (treadmill)	1.94	58.0	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	0.67	40.0	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	2.00	69.0	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	4.00	86.0	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	0.67	36.5	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	2.00	63.5	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	3.67	84.5	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	0.67	37.0	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	2.00	62.0	MAOD
(BYRNES & KEARNEY, 1997)	kayak (ergometer)	3.67	82.0	MAOD
(GASTIN, P.B. & LAWSON, D.L., 1994)	cycle (ergometer)	1.50	53.0	MAOD
(FAINA ET AL., 1997)	swim (flume)	5.03	83.2	MAOD
(BANGSBO ET AL., 1993)	run (treadmill)	2.98	74.3	MAOD
(GASTIN, P.B. & LAWSON,	cycle (ergometer)	1.50	56.0	MAOD

D.L., 1994)				
(NAKAGAKI ET AL., 2008)	kayak (ergometer)	0.33	11.8	MAOD
(NAKAGAKI ET AL., 2008)	kayak (ergometer)	0.67	29.0	MAOD
(NAKAGAKI ET AL., 2008)	kayak (ergometer)	2.00	57.0	MAOD
(NAKAGAKI ET AL., 2008)	kayak (ergometer)	4.00	74.0	MAOD
(NAKAGAKI ET AL., 2008)	kayak (ergometer)	10.00	91.7	MAOD
(HETTINGA ET AL., 2007)	cycle (ergometer)	1.94	50.6	MAOD
(HETTINGA ET AL., 2007)	cycle (ergometer)	1.95	50.8	MAOD
(HETTINGA ET AL., 2007)	cycle (ergometer)	1.97	51.3	MAOD
(CRAIG & MORGAN, 1998)	run (treadmill)	1.90	61.2	MAOD
(CRAIG & MORGAN, 1998)	run (treadmill)	2.40	73.1	MAOD
(GARDNER ET AL., 2003)	cycle (ergometer)	2.00	69.2	MAOD
(CRAIG ET AL., 1995)	cycle (ergometer)	2.00	67.3	MAOD
(CRAIG ET AL., 1995)	cycle (ergometer)	2.00	63.5	MAOD
(CRAIG ET AL., 1995)	cycle (ergometer)	5.00	84.9	MAOD
(CRAIG ET AL., 1995)	cycle (ergometer)	5.00	85.8	MAOD
(RODRIGUES & MADER, 2011)	swim (?)	0.80	41.0	Pcr-La-O_2
(RODRIGUES & MADER, 2011)	swim (?)	14.8	86.0	Pcr-La-O_2
(RODRIGUES & MADER, 2011)	swim (?)	1.75	58.0	Pcr-La-O_2
(RODRIGUES & MADER, 2011)	swim (?)	3.75	73.0	Pcr-La-O_2
(HERMSDORF ET AL., 2011)	figure skating	3.77	74.1	Pcr-La-O_2
(RODRIGUES & MADER, 2011)	swim (?)	0.40	4.0	Pcr-La-O_2
(RODRIGUES & MADER, 2011)	swim (?)	7.80	82.0	Pcr-La-O_2
(SERRESSE ET AL., 1988)	cycle (ergometer)	0.17	3.0	Pcr-La-O_2
(SERRESSE ET AL., 1988)	cycle (ergometer)	0.50	28.0	Pcr-La-O_2
(SERRESSE ET AL., 1988)	cycle (ergometer)	1.50	46.0	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	2.00	63.9	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	4.00	76.6	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	6.00	82.4	Pcr-La-O_2
(CAPELLI ET AL., 1998)	swim (field)	0.44	19.4	Pcr-La-O_2
(CAPELLI ET AL., 1998)	swim (field)	0.96	37.7	Pcr-La-O_2
(CAPELLI ET AL., 1998)	swim (field)	2.10	63.0	Pcr-La-O_2
(DUFFIELD ET AL., 2004)	run (field)	0.22	10.9	Pcr-La-O_2
(DUFFIELD ET AL., 2005b)	run (field)	5.30	82.0	Pcr-La-O_2
(DUFFIELD ET AL., 2004)	run (field)	0.45	22.0	Pcr-La-O_2
(DUFFIELD ET AL., 2005b)	run (field)	11.6	92.0	Pcr-La-O_2
(DUFFIELD ET AL., 2005a)	run (field)	1.00	37.0	Pcr-La-O_2
(DUFFIELD ET AL., 2005a)	run (field)	2.50	68.6	Pcr-La-O_2
(DORIA ET AL., 2009)	kata	2.60	58.5	Pcr-La-O_2
(DORIA ET AL., 2009)	kata	3.00	61.4	Pcr-La-O_2
(SMITH & HILL, 1991)	cycle (ergometer)	0.50	16.0	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	6.00	81.9	Pcr-La-O_2
Own data	kayak (ergometer)	0.67	31.1	Pcr-La-O_2
Own data	kayak (ergometer)	2.00	57.8	Pcr-La-O_2

Own data	kayak (ergometer)	0.67	32.4	Pcr-La-O_2
Own data	kayak (ergometer)	4.00	76.2	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	2.00	61.5	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	4.00	75.2	Pcr-La-O_2
(HARTMANN, 1987)	row (Gjessing ergometer)	6.00	83.5	Pcr-La-O_2
(DUFFIELD ET AL., 2004)	run (field)	0.19	8.9	Pcr-La-O_2
(DUFFIELD ET AL., 2005b)	run (field)	4.40	81.0	Pcr-La-O_2
(DUFFIELD ET AL., 2004)	run (field)	0.40	20.7	Pcr-La-O_2
(DUFFIELD ET AL., 2005b)	run (field)	9.60	93.0	Pcr-La-O_2
(DUFFIELD ET AL., 2005a)	run (field)	0.90	35.2	Pcr-La-O_2
(DUFFIELD ET AL., 2005a)	run (field)	2.10	63.4	Pcr-La-O_2
(DE CAMPOS MELLO ET AL., 2009)	row (water)	8.58	87.0	Pcr-La-O_2
(DORIA ET AL., 2009)	kata	2.30	50.2	Pcr-La-O_2
(DORIA ET AL., 2009)	kata	4.00	74.0	Pcr-La-O_2
(BUSSWEILER & HARTMANN, 2012)	karate	0.53	19.0	Pcr-La-O_2
(ZAMPARO ET AL., 2009)	kayak (water)	1.03	40.5	Pcr-La-O_2
(ZAMPARO ET AL., 2009)	kayak (water)	2.25	60.4	Pcr-La-O_2
(ZAMPARO ET AL., 2009)	kayak (water)	4.82	83.3	Pcr-La-O_2
(ZAMPARO ET AL., 2009)	kayak (water)	9.47	89.5	Pcr-La-O_2
(ZAMPARO ET AL., 1999)	canoe slalom (water)	1.43	45.2	Pcr-La-O_2
(BENEKE ET AL., 2004)	kata and kumite	4.35	77.8	Pcr-La-O_2
Own data	canoe (water)	0.67	31.3	Pcr-La-O_2
Own data	kayak (ergometer)	4.00	76.5	Pcr-La-O_2
Own data	kayak (water)	4.00	75.0	Pcr-La-O_2
Own data	canoe (water)	4.00	75.3	Pcr-La-O_2
Own data	run (field)	4.00	76.7	Pcr-La-O_2
Own data	run (treadmill)	4.00	75.8	Pcr-La-O_2
Own data	cycle (ergometer)	4.00	75.2	Pcr-La-O_2
Own data	arm crank (ergometer)	4.00	68.9	Pcr-La-O_2
(HILL, 1999)	run (treadmill)	1.02	38.0	Pcr-La-O_2
(HILL, 1999)	run (treadmill)	2.43	67.0	Pcr-La-O_2
(HILL, 1999)	run (treadmill)	5.15	83.0	Pcr-La-O_2
(HILL, 1999)	run (treadmill)	0.82	37.0	Pcr-La-O_2
(HILL, 1999)	run (treadmill)	2.00	61.0	Pcr-La-O_2
(HILL, 1999)	run (treadmill)	4.10	80.0	Pcr-La-O_2
(GUIDETTI ET AL., 2000)	rhythmic gymnastics	1.50	49.0	Pcr-La-O_2
(ZAMPARO ET AL., 2006)	canoe slalom (water)	1.47	47.0	Pcr-La-O_2
(DE CAMPOS MELLO ET AL., 2009)	row (ergometer with slide)	6.63	84.0	Pcr-La-O_2
(DE CAMPOS MELLO ET AL., 2009)	row (ergometer without slide)	6.70	84.0	Pcr-La-O_2

Appendix 6: W_{AER} % of Maximal Exercises based on Data from MAOD, Pcr-La-O_2 and Total

Duration	MAOD	Pcr-La-O_2	Total
[min]	%	%	%
0.5	32.2	25.2	29.5
1	47.3	41.1	44.9
2	62.5	57.1	60.4
3	71.4	66.4	69.4
4	77.7	73.0	75.8
5	82.6	78.1	80.8
6	86.6	82.3	84.8
7	90.0	85.9	88.3
8	92.9	88.9	91.2
9	95.5	91.6	93.8
10	97.8	94.1	96.2

Appendix 7: W_{AER} % of Maximal Paddling in Chapter 3

				W_{AER} %
Study 1	JF-40 s	MAOD	M	36.1
		Pcr-La-O_2	M	30.6
	JF-2 min	MAOD	M	60.7
		Pcr-La-O_2	M	57.5
Study 2	AM-4 min	W	M	75.0
		E	M	76.5
Study 2	AM-4 min	E	M	76.5
	JM-4 min	E	M	76.2
Study 1	JF-40 s	MAOD	SD	3.7
		Pcr-La-O_2	SD	3.5
	JF-2 min	MAOD	SD	12.2
		Pcr-La-O_2	SD	4.5
Study 2	AM-4 min	W	SD	4.0
		E	SD	4.0
Study 2	AM-4 min	E	SD	4.0
	JM-4 min	E	SD	3.9

Appendix 8: Energetic Profile of Kayaking in Chapter 4

		W_{PCR}	W_{BLC}	W_{AER}	W_{PCR}	W_{BLC}	W_{AER}	E_{PCR}	E_{BLA}	E_{AER}
		kJ	kJ	kJ	%	%	%	kw	kw	kw
40 s-F	M	31	21	23	41.1	27.8	31.1	0.77	0.52	0.59
40 s-M	M	41	33	35	37.8	29.8	32.4	1.03	0.81	0.87
120 s-F	M	33	34	92	20.9	21.3	57.8	0.28	0.28	0.77
240 s-M	M	46	40	275	12.7	11.2	76.2	0.19	0.17	1.15
40s-F	SD	6	4	4	6.8	5.0	3.4	0.16	0.11	0.10
40s-M	SD	9	11	6	6.1	7.9	4.6	0.24	0.27	0.16
120s-F	SD	6	6	11	3.1	3.2	3.9	0.05	0.05	0.09
240s-M	SD	13	8	35	3.2	1.9	3.9	0.05	0.03	0.15

Appendix 9: Physiological and Ergometric Process of 40s, 120s, and 240s Maximal Kayaking (Data)

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1	36	13	23	11	27	12	72	7	73	6	64	10	61	6	55	3	58	7	80	9	77	6	74	14	65	4	65	5	62	4
2	34	12	22	9	29	13	73	8	76	4	65	10	76	6	71	5	74	8	87	8	87	9	82	15	79	3	80	5	78	5
3	32	11	23	7	31	11	75	6	77	4	66	9	82	7	78	5	79	9	90	9	86	8	81	16	87	4	87	4	85	5
4	32	10	24	7	34	11	77	5	78	4	67	9	86	6	83	5	82	9	89	9	90	6	82	16	90	4	91	4	89	6
5	35	15	25	8	32	10	78	5	79	5	69	9	90	6	84	5	83	11	93	6	89	8	82	13	94	3	94	4	92	6
6	37	15	28	9	31	11	79	5	80	5	70	9	90	5	85	4	84	9	95	6	87	7	83	14	96	3	95	3	93	5
7	38	15	30	6	31	13	81	6	81	5	71	8	92	5	85	5	84	10	94	6	89	6	80	17	96	4	96	3	94	6
8	40	15	35	9	33	14	82	5	82	6	73	8	93	4	86	5	85	11	93	6	89	6	80	15	97	3	96	3	94	6
9	42	15	39	15	33	15	83	5	83	6	74	8	91	4	85	6	84	10	94	7	89	6	79	15	97	3	97	3	94	6
10	47	18	43	13	35	12	85	5	84	5	75	8	95	5	86	6	83	10	94	6	88	8	78	20	98	3	97	3	93	7
11	51	17	49	14	33	14	85	5	85	6	77	7	94	5	88	6	85	11	95	6	90	8	80	16	97	4	97	3	93	6
12	53	19	49	13	36	18	86	5	85	6	78	7	93	6	86	4	84	10	92	7	92	5	81	15	98	3	98	3	94	6
13	57	20	49	12	36	19	87	5	86	6	79	6	94	4	86	6	84	10	95	5	93	4	81	16	99	1	98	3	94	6
14	66	18	47	13	40	21	88	5	86	6	80	6	95	5	87	5	84	10	94	6	92	5	81	16	99	1	98	2	94	6
15	69	18	47	16	41	20	89	5	87	6	81	6	95	4	88	8	84	11	96	7	93	4	78	16	99	2	98	2	94	6
16	69	18	50	19	44	18	90	5	88	6	82	6	95	4	88	6	84	10	96	5	91	5	79	15	99	1	97	3	94	6
17	70	20	56	16	47	18	91	5	88	6	83	6	94	4	87	7	82	11	94	6	92	7	79	16	99	2	97	3	93	6
18	69	21	63	18	50	19	92	5	89	6	83	5	95	5	89	8	83	11	94	5	91	8	79	18	99	1	97	2	93	6
19	67	20	66	19	55	18	93	4	89	6	84	5	93	3	88	5	81	10	94	4	90	7	77	16	99	1	97	3	93	7
20	73	15	62	19	55	17	93	4	90	6	85	5	95	4	87	7	81	10	94	5	90	6	77	18	99	1	97	3	92	6
21	77	11	62	19	57	16	94	3	90	6	85	5	94	4	89	7	81	12	93	7	95	5	76	17	99	1	97	2	92	7
22	82	11	58	19	59	15	95	2	91	6	86	5	94	5	89	7	81	11	93	5	93	5	77	17	99	2	97	3	92	7
23	84	10	58	20	62	14	96	2	91	6	86	5	94	4	89	6	81	10	93	6	92	6	76	17	99	1	97	3	92	7
24	86	11	60	22	65	16	96	2	91	5	86	5	95	5	90	7	82	12	92	7	91	5	74	18	99	2	97	3	92	7
25	86	15	70	18	63	13	97	2	92	5	87	5	93	4	89	7	80	12	92	5	89	6	75	16	99	2	97	3	92	7
26	85	13	75	15	65	10	97	2	92	4	87	5	94	4	89	8	80	11	93	5	88	5	76	17	99	1	97	3	92	7
27	85	9	75	12	67	10	97	1	92	5	88	5	94	5	90	5	81	11	92	6	94	5	76	18	99	1	98	3	92	7
28	82	13	80	12	69	13	98	1	92	4	88	4	95	4	89	7	81	11	92	7	93	6	75	17	99	1	97	4	92	7
29	82	12	79	9	68	17	98	1	93	5	88	4	95	4	88	5	82	11	94	7	90	8	75	15	99	2	98	3	92	7
30	84	11	80	9	68	20	98	1	93	5	88	5	95	4	89	7	81	11	91	8	93	6	76	19	98	2	99	1	92	7
31	89	12	78	8	70	16	98	1	93	4	89	4	95	4	89	5	81	11	92	8	90	10	75	16	99	2	98	2	92	7
32	88	9	75	10	69	16	99	1	93	4	89	4	95	4	88	5	81	11	96	4	89	5	75	16	99	1	99	1	92	7
33	90	9	73	11	72	13	99	1	93	4	89	4	96	4	89	6	81	11	93	6	90	4	76	17	99	1	98	1	92	7

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
34	92	10	74	15	75	8	99	1	93	4	89	4	96	4	88	4	81	10	93	7	89	6	74	16	99	1	98	1	91	7
35	91	11	74	16	75	10	99	1	94	4	89	4	97	4	89	6	81	11	94	6	86	9	74	17	99	1	98	1	91	7
36	93	8	73	19	76	11	99	1	94	4	89	4	97	3	89	6	81	12	95	6	84	11	76	18	100	1	96	4	91	7
37	92	10	76	12	75	9	99	1	94	4	90	4	96	4	89	7	82	12	95	8	89	6	75	16	99	1	97	2	91	7
38	94	7	73	12	75	10	100	0	94	4	90	4	98	3	87	7	80	11	95	8	89	8	75	17	99	1	98	2	91	7
39	94	4	75	13	75	10	100	0	94	4	90	4	98	4	87	6	80	10	97	6	92	6	73	17	99	1	98	2	91	7
40	95	4	77	9	75	10	100	0	94	4	90	4	100	0	89	6	79	10	100	0	88	10	73	17	100	0	98	2	91	7
41			81	10	77	10			94	4	90	4			88	5	78	10			91	8	73	16			98	2	91	7
42			86	10	78	10			95	4	90	4			90	6	80	10			87	9	71	15			98	2	91	7
43			80	7	77	10			95	4	90	4			89	6	79	11			89	10	72	16			98	2	91	7
44			79	13	78	11			95	3	90	4			89	5	79	11			88	8	71	17			98	2	90	7
45			77	14	79	10			95	3	90	4			89	5	78	11			89	9	73	15			98	2	90	7
46			78	17	80	9			95	3	91	4			88	5	78	11			88	9	73	14			98	2	90	7
47			83	12	78	8			95	3	91	4			88	7	79	10			89	9	72	14			98	2	90	7
48			80	8	80	7			95	3	91	4			89	6	79	10			88	10	70	16			98	2	90	7
49			80	10	80	7			95	3	91	4			87	6	79	11			87	7	69	16			98	2	90	7
50			79	12	81	8			96	3	91	4			88	6	78	10			88	9	70	14			98	2	89	7
51			84	12	81	10			96	3	91	3			88	4	77	10			85	11	69	14			98	3	89	6
52			85	10	81	11			96	3	91	3			88	6	78	10			85	9	70	15			97	3	90	6
53			86	12	79	10			96	3	91	3			88	6	77	10			87	10	69	15			97	3	89	6
54			83	9	79	9			96	3	91	3			88	6	77	9			87	11	69	15			97	2	89	6
55			80	5	79	9			96	2	91	3			90	7	78	11			86	9	70	15			97	2	89	7
56			78	9	79	9			96	3	91	3			89	9	77	10			85	13	70	16			97	3	89	7
57			80	8	79	8			96	2	91	3			87	5	77	10			87	9	69	15			97	2	89	7
58			79	10	80	9			96	2	91	3			89	4	77	10			85	7	68	16			97	2	89	7
59			80	12	80	6			97	2	92	3			87	7	76	9			88	8	68	14			97	2	89	7
60			81	13	80	7			97	2	92	3			86	4	76	10			86	10	68	14			97	3	89	6
61			82	14	80	7			97	2	92	3			86	5	77	10			86	10	67	14			97	3	88	6
62			82	13	80	8			97	2	92	3			86	6	77	10			83	10	68	14			98	2	88	6
63			83	11	79	9			97	2	92	3			88	5	77	9			84	11	67	14			98	2	88	6
64			79	14	78	9			97	2	92	3			85	6	77	9			84	10	69	14			97	3	89	6
65			80	10	79	9			97	2	92	3			86	8	76	9			81	11	67	13			97	2	88	6
66			82	9	81	8			97	1	92	3			86	7	77	10			82	10	68	13			97	3	89	6

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
67			81	10	82	9			97	1	92	3			84	7	76	9			84	6	69	15			97	2	89	6
68			82	9	82	8			97	1	92	3			86	8	76	10			85	6	68	12			97	2	89	6
69			79	11	82	8			98	1	92	3			85	7	77	11			86	8	68	14			97	2	88	6
70			79	10	83	9			98	1	92	3			86	5	76	11			84	8	69	15			97	2	89	6
71			79	7	82	10			98	1	92	3			85	6	76	9			79	8	69	12			97	3	89	6
72			81	10	81	10			98	1	93	3			85	5	76	9			78	10	67	13			96	3	88	6
73			82	10	82	10			98	1	93	3			86	5	75	8			80	11	65	14			96	3	88	6
74			80	11	83	9			98	1	93	3			86	6	76	10			82	11	66	14			96	3	88	6
75			82	8	81	11			98	1	93	3			87	6	78	11			81	8	67	13			96	3	88	6
76			83	9	82	10			98	1	93	3			87	8	76	11			83	10	67	13			96	3	88	6
77			78	10	81	10			98	1	93	3			84	7	76	11			78	11	67	13			96	4	88	6
78			76	11	82	8			98	1	93	3			84	9	76	9			81	12	66	14			96	3	88	6
79			79	5	83	8			98	1	93	3			83	8	75	9			83	13	67	13			96	4	88	6
80			83	5	82	8			98	1	93	3			86	7	77	10			83	10	67	13			96	3	88	6
81			85	5	82	7			98	1	93	3			87	6	75	9			81	10	67	11			96	3	88	6
82			82	6	79	8			98	1	93	3			85	5	76	10			81	12	67	14			96	4	88	6
83			83	5	80	8			98	1	93	3			86	7	74	9			82	12	66	12			96	4	88	6
84			86	6	81	6			98	1	93	2			86	7	76	10			82	14	66	16			96	4	88	6
85			83	8	82	8			98	1	93	2			85	8	75	10			80	10	68	14			96	4	88	6
86			82	10	82	7			98	1	93	2			85	8	76	10			83	11	66	14			96	4	88	6
87			84	9	82	8			98	1	93	2			83	7	77	9			80	12	67	14			96	4	88	6
88			80	12	82	9			98	1	93	2			83	7	77	10			82	10	65	16			96	4	88	6
89			80	14	83	8			99	1	94	2			85	7	76	11			81	10	66	12			96	4	88	6
90			79	13	83	7			99	1	94	2			86	7	76	9			84	13	65	13			96	4	87	6
91			78	13	84	7			99	1	94	2			86	8	76	10			80	12	67	13			96	4	88	6
92			79	13	83	7			99	1	94	2			86	7	76	9			82	15	66	15			96	4	88	6
93			81	9	82	8			99	1	94	2			88	5	75	8			85	11	64	13			96	4	87	6
94			81	11	81	8			99	1	94	2			87	4	75	8			81	14	63	11			96	4	87	6
95			81	8	80	12			99	1	94	2			87	5	75	9			80	9	65	13			96	4	87	6
96			79	13	83	8			99	1	94	2			87	9	75	10			81	14	65	14			96	3	87	6
97			80	15	82	8			99	1	94	2			86	10	75	10			81	14	64	13			97	3	87	6
98			77	14	84	9			99	1	94	2			86	8	75	10			80	12	65	13			96	4	87	6
99			79	15	83	9			99	0	94	2			87	6	75	9			86	11	67	14			97	3	87	6

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
100			79	13	81	8			99	0	94	2			89	3	75	10			85	8	63	13			97	3	87	6
101			80	9	80	9			99	1	94	2			89	4	76	9			87	10	64	13			97	3	87	6
102			80	9	79	11			99	1	94	2			90	4	76	9			89	14	65	14			97	3	87	6
103			81	10	81	11			99	0	94	2			89	5	76	9			86	11	64	13			97	3	87	6
104			80	11	83	8			99	0	94	2			90	6	75	10			86	9	63	14			97	3	87	6
105			78	10	83	8			99	0	94	2			89	7	75	9			85	9	65	14			97	3	87	6
106			79	12	83	8			99	0	94	2			87	8	76	10			85	11	65	14			98	3	87	6
107			81	11	82	10			100	0	94	2			90	10	76	9			79	12	65	12			97	3	87	6
108			80	11	82	8			100	0	94	2			91	8	76	9			83	10	66	13			97	3	87	6
109			79	11	82	10			100	0	94	2			90	5	76	10			85	11	65	13			97	3	87	6
110			77	14	83	9			100	0	94	2			92	6	75	9			83	13	65	13			97	3	87	6
111			75	15	82	10			100	0	94	2			91	7	75	9			88	8	66	14			97	3	87	6
112			76	12	84	8			100	0	94	2			94	6	75	9			91	11	67	13			98	3	87	6
113			81	8	83	8			100	0	94	2			90	13	76	8			84	23	66	14			95	7	88	6
114			83	8	82	10			100	0	94	2			95	5	75	10			91	9	66	14			98	2	87	6
115			80	11	82	10			100	0	94	2			96	6	76	9			93	8	67	14			98	2	88	6
116			82	7	83	9			100	0	95	2			94	8	77	10			89	13	66	12			99	1	88	6
117			85	7	82	10			100	0	95	2			96	5	76	8			90	10	64	13			99	1	87	6
118			86	8	84	9			100	0	95	2			96	4	76	9			96	6	65	13			100	1	87	6
119			85	7	83	9			100	0	95	2			98	3	75	9			96	6	67	13			100	0	87	6
120			84	7	83	10			100	0	95	2			100	0	76	9			100	0	67	12			100	0	87	6
121					84	8					95	2					75	9					66	13					88	6
122					85	8					95	2					76	10					66	13					87	6
123					84	9					95	2					76	9					65	13					87	6
124					83	9					95	2					75	9					64	12					87	6
125					83	9					95	2					76	8					64	12					87	6
126					83	9					95	2					76	8					63	11					87	6
127					84	9					95	2					76	9					63	11					87	5
128					83	9					95	2					76	9					66	12					87	5
129					84	8					95	2					76	10					67	12					87	5
130					85	8					95	2					77	9					66	12					87	5
131					83	12					95	2					77	9					65	13					87	6
132					83	11					95	2					77	8					64	13					87	6

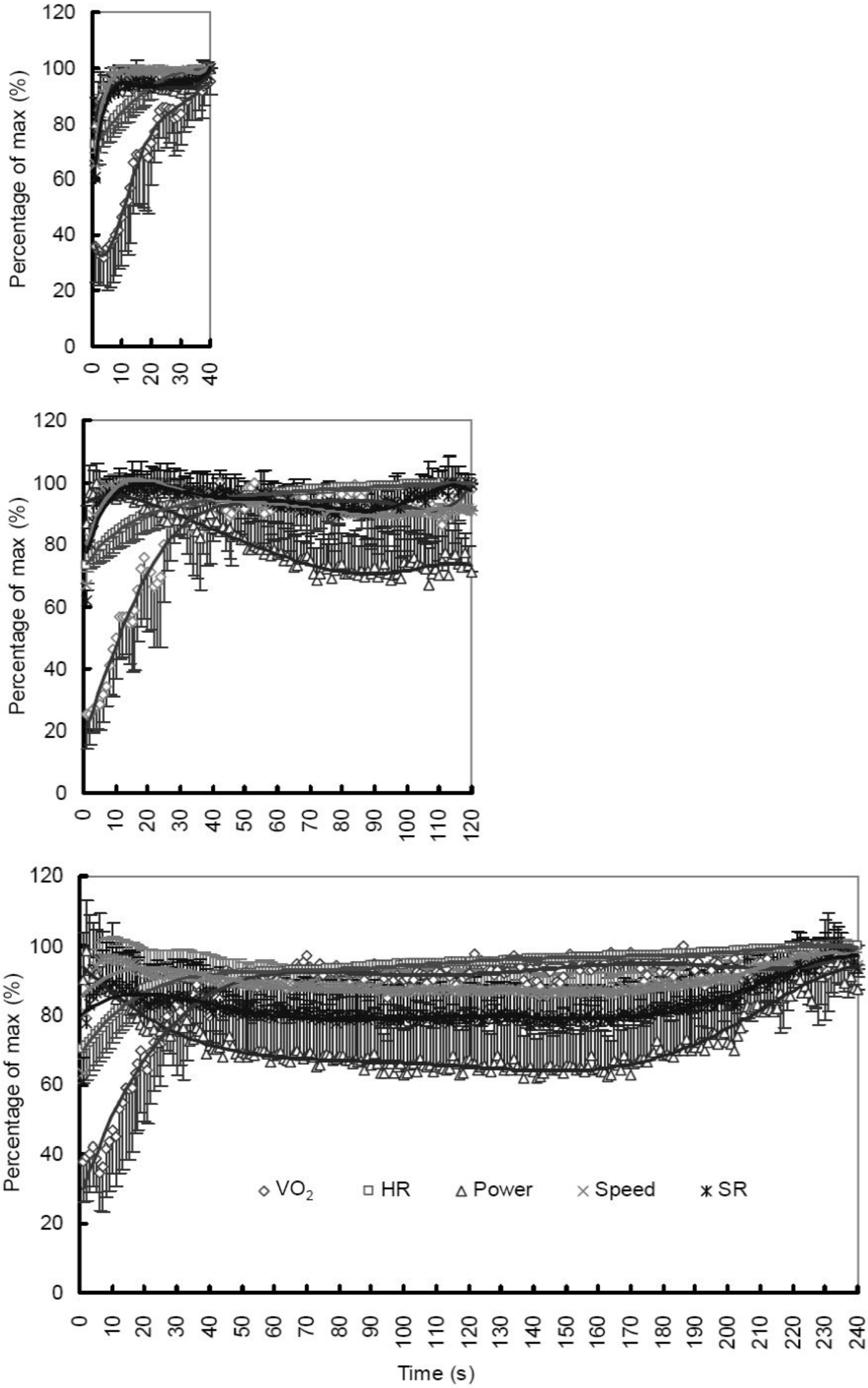
	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
133					84	8					95	2					76	9					65	14					87	6
134					84	8					95	2					76	10					67	13					88	6
135					85	6					95	2					76	10					65	13					87	6
136					85	7					96	2					76	9					65	13					87	6
137					83	9					96	2					76	9					63	12					87	6
138					82	13					96	2					75	9					66	13					87	6
139					85	7					96	2					75	9					65	11					87	6
140					83	10					96	2					75	8					64	11					87	5
141					83	13					96	2					77	8					64	12					87	5
142					82	12					96	2					76	10					64	12					87	5
143					85	10					96	2					75	9					64	11					86	5
144					84	7					96	2					76	9					65	11					87	5
145					81	11					96	2					76	8					65	11					87	5
146					79	14					96	2					76	9					65	13					87	6
147					80	11					96	2					77	9					65	10					87	5
148					81	11					96	1					76	10					65	12					87	5
149					83	9					96	1					75	9					64	12					87	5
150					86	7					96	1					75	8					65	11					87	5
151					87	7					96	1					76	9					65	12					87	5
152					86	8					96	2					76	8					65	11					87	5
153					86	7					96	1					76	8					64	10					87	5
154					84	10					96	1					75	8					65	11					87	5
155					85	10					96	1					75	9					65	12					87	5
156					84	8					96	1					76	8					65	12					87	6
157					84	9					96	1					77	9					66	11					87	5
158					85	10					97	1					76	9					67	11					87	5
159					85	12					97	1					76	9					65	11					87	5
160					85	10					97	1					77	8					64	12					87	5
161					85	10					97	1					75	8					65	12					87	5
162					85	7					97	1					76	9					65	12					87	5
163					86	6					97	1					76	9					64	12					87	5
164					86	7					97	1					75	8					63	10					87	5
165					86	8					97	1					74	8					65	10					87	5

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
166					85	8					97	1					75	7					66	11					87	5
167					85	8					97	1					76	8					64	12					87	5
168					86	7					97	1					77	10					67	10					87	5
169					86	7					97	1					77	9					66	11					87	5
170					87	8					97	1					77	8					65	13					87	5
171					86	7					97	1					76	8					66	12					88	6
172					85	8					97	1					76	8					64	11					87	5
173					84	9					97	1					77	9					66	12					88	5
174					83	13					97	1					77	9					67	11					88	5
175					84	11					97	1					77	8					66	11					88	5
176					85	9					97	1					76	9					66	11					88	5
177					85	8					97	1					77	7					67	11					88	5
178					84	9					97	1					77	7					69	11					88	5
179					84	12					97	1					77	9					69	11					88	5
180					86	11					97	1					77	10					68	12					89	5
181					85	12					97	1					77	10					67	11					89	5
182					83	12					97	1					77	9					66	10					88	5
183					82	10					97	1					78	8					68	11					88	5
184					84	10					97	1					78	8					68	11					88	5
185					86	8					97	1					78	8					69	11					89	5
186					87	7					97	1					77	9					68	13					88	6
187					86	6					97	1					77	9					69	11					89	5
188					86	8					97	1					79	11					69	11					89	5
189					85	11					98	1					79	10					68	11					89	5
190					83	14					98	1					78	9					68	11					89	5
191					84	12					98	1					79	8					70	12					89	5
192					83	14					98	1					77	7					67	11					89	5
193					82	15					98	1					79	9					69	12					89	5
194					82	14					98	1					78	9					70	12					89	5
195					84	11					98	1					79	10					70	13					89	5
196					85	10					98	1					78	9					71	12					89	6
197					84	11					98	1					79	9					69	13					90	5
198					85	9					98	1					78	10					72	12					90	6

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
199					83	13					98	1					79	10					71	12					90	5
200					85	12					98	1					80	10					71	12					90	5
201					87	12					98	1					80	10					71	12					90	5
202					88	11					98	1					79	9					70	13					90	5
203					87	12					98	1					79	9					70	9					90	5
204					85	15					98	1					79	8					72	10					90	5
205					86	14					98	1					81	9					74	10					90	4
206					84	12					98	1					81	9					76	10					91	4
207					82	12					98	1					81	8					76	9					92	4
208					83	7					98	1					81	8					76	9					92	4
209					84	7					99	1					83	8					78	9					92	4
210					84	9					99	1					84	9					76	9					93	4
211					84	10					99	1					84	9					78	9					93	4
212					85	12					99	1					83	9					78	9					93	4
213					86	10					99	1					83	8					78	12					93	4
214					84	10					99	1					84	8					77	10					93	4
215					85	11					99	1					85	8					77	9					93	4
216					82	16					99	1					84	8					81	9					93	4
217					81	14					99	1					84	7					80	8					94	4
218					83	12					99	1					83	8					80	10					94	4
219					85	10					99	1					85	9					81	11					94	4
220					86	9					99	1					85	9					84	10					95	4
221					86	8					99	0					87	9					85	10					95	4
222					87	9					99	1					87	10					85	9					95	4
223					85	10					99	1					87	9					83	10					96	4
224					86	11					99	0					87	9					84	8					96	4
225					84	10					99	0					87	8					84	9					96	4
226					82	11					99	0					88	7					83	10					96	3
227					82	12					99	0					89	7					90	8					97	3
228					80	15					99	0					92	7					90	8					97	3
229					83	11					99	0					92	6					88	9					98	3
230					83	12					100	0					93	6					92	7					98	2
231					83	10					100	0					92	5					90	10					98	2

	VO_2						HR						SR						Power						Speed					
	40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s		40s		120s		240s	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
232					85	10					100	0					92	5					89	7					98	1
233					84	9					100	0					94	5					92	8					99	1
234					85	8					100	0					96	5					93	7					99	1
235					85	9					100	0					96	5					92	7					99	1
236					85	11					100	0					95	4					92	8					98	5
237					85	12					100	0					97	3					96	5					99	3
238					87	10					100	0					98	3					97	4					99	2
239					88	11					100	0					98	4					97	4					100	1
240					88	9					100	0					100	0					100	0					100	0

Appendix 10: Physiological and Ergometric Process of 40s, 120s, and 240s Maximal Kayaking (Figure in M ± SD)



Appendix 11: VO_2 and C at Different Speed in Step Test and Maximal Test

	Speed	VO_2	C
	m/s	l/min	kJ/m
Step1	2.9	2.697	0.25
	2.9	2.378	0.24
	3.0	2.826	0.26
	3.0	2.529	0.25
	3.1	2.607	0.24
	3.0	2.861	0.25
	3.0	2.562	0.23
	3.0	2.895	0.25
Step2	3.1	3.2	0.30
	3.1	2.9	0.26
	3.0	2.9	0.28
	3.1	2.8	0.25
	3.3	2.8	0.23
	3.1	3.2	0.28
	3.2	3.0	0.26
	3.1	3.0	0.29
Step3	3.3	3.6	0.31
	3.3	3.6	0.31
	3.3	3.4	0.29
	3.2	3.4	0.30
	3.2	2.8	0.24
	3.4	3.6	0.30
	3.3	3.4	0.29
	3.4	3.6	0.30
Step4	3.7	4.6	0.39
	3.3	3.5	0.33
	3.7	4.9	0.39
	3.4	3.9	0.32
	3.5	4.2	0.37
	3.6	4.2	0.35
	3.3	3.6	0.32
	3.5	4.2	0.37
Max	4.0		0.44
	3.9		0.48
	4.1		0.52
	3.7		0.45
	3.8		0.41
	4.1		0.46
	4.0		0.48
	4.1		0.45

Appendix 12: C in Different Locomotion

	Speed [m/s]									
	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5
Kayaking	0	0.00	0.02	0.05	0.10	0.16	0.24	0.34	0.46	0.60
Front Crawl	0	0.24	0.63	1.10	1.63	2.22				
Gondala	0	0.05	0.16	0.31	0.49	0.72	0.97			
Rowing	0	0.00	0.02	0.04	0.07	0.12	0.18	0.25	0.34	0.44
Canoeing		0.006	0.02	0.06	0.11	0.17	0.25	0.35	0.46	0.59

Data from front crawl (CAPELLI ET AL., 1998), gondola (CAPELLI ET AL., 1990), kayaking (ZAMPARO ET AL., 1999), rowing (DI PRAMPERO ET AL., 1971), and canoeing (own data from this study)

Appendix 13: W_{AER} % and Time Constant from Chapter 6

T [s]	W_{AER} %	T [s]	W_{AER} %
24.1	76.2	17.7	73.0
12	81.5	16.7	79.4
9.2	74.1	16.7	79.5
13.5	77.6	17.8	75.4
9.5	77.4	11.5	80.6
28.3	69.1	11.6	68.4
15.9	77.2	17.5	75.1
20.7	71.7	19.9	69.6
20.7	74.6	27.4	67.6
21	74.5	15.9	68.6
16.8	71.3	23.5	66.5
13.3	71.9	14.7	61.9
18.7	79.8	22.5	69.3
17	76.6	34.7	66.1
17.3	77.3	30.4	74.0
18	76.1	17.2	69.3
18.9	83.0	29.8	68.5
19.1	80.4	35.5	70.7
16.2	78.4	15	74.0
19.7	73.5	10.4	76.4
20.4	78.2	16	77.1
21.1	78.7	11	76.0
14.9	77.2	13.1	69.3
19.5	72.0		
12.1	83.8		
12.5	65.2		
10.6	78.3		
14.1	74.4		
10.5	70.9		
12	77.6		
18.3	78.8		
13.7	78.7		
13.6	77.6		
17.1	75.4		
22.6	72.1		
16.9	80.7		
17.2	81.0		
8.9	71.4		
27.7	74.4		
22	74.6		
10.6	75.9		
10.6	74.3		
14.7	75.2		
14.8	74.4		
6.5	74.4		

Appendix 14: VO_2 of Five Studies Maximal Exercises

	Running		Cylcing		Arm cranking		Kayaking		Canoeing	
	M	SD	M	SD	M	SD	M	SD	M	SD
1	19	6	22	8	17	5	18	6	20	5
2	20	7	23	8	19	5	17	7	22	10
3	23	7	24	8	18	4	18	9	24	9
4	27	6	27	8	18	4	17	10	26	9
5	31	8	29	7	19	5	20	10	34	11
6	33	10	30	8	21	5	21	12	41	14
7	34	9	30	8	23	6	27	14	43	10
8	34	10	31	9	24	8	30	13	43	8
9	34	10	32	10	26	9	29	12	44	8
10	34	11	33	9	28	9	31	9	44	7
11	34	11	34	8	30	8	30	8	45	8
12	34	10	34	8	33	10	27	9	44	8
13	35	11	35	8	34	9	23	11	44	8
14	36	11	37	8	35	10	20	12	43	6
15	38	12	37	8	36	9	24	15	43	6
16	40	11	39	9	37	10	31	15	44	6
17	43	11	40	9	37	9	36	11	47	6
18	47	11	42	10	38	8	39	9	48	5
19	50	10	45	10	37	7	42	9	50	5
20	52	10	48	13	38	7	46	10	52	6
21	55	9	50	13	37	7	46	14	53	6
22	58	9	52	14	39	8	49	18	54	6
23	61	8	55	13	39	7	53	13	56	5
24	63	9	57	12	40	7	53	13	59	4
25	65	8	59	12	44	10	52	13	61	3
26	67	7	60	12	45	11	51	17	66	3
27	69	7	62	11	48	9	53	12	66	4
28	70	7	64	11	49	10	55	12	68	5
29	71	7	65	10	52	11	59	12	69	5
30	72	7	66	10	53	11	64	11	71	5
31	73	7	65	10	53	11	65	11	72	5
32	74	6	67	10	54	9	65	11	73	6
33	75	5	67	10	56	10	64	16	74	6
34	76	5	68	10	57	9	62	21	76	6
35	76	6	69	9	58	10	62	21	77	6
36	77	6	70	9	59	11	63	15	77	7
37	77	5	72	9	59	12	62	13	77	7
38	77	5	73	9	60	10	63	10	78	6
39	78	5	74	9	63	8	65	14	78	7
40	79	6	75	8	65	7	66	18	79	6
41	79	6	76	8	65	8	65	23	79	5
42	80	6	77	9	67	9	65	23	80	6
43	81	6	78	8	67	11	69	20	79	7
44	82	6	78	9	66	11	72	15	80	8
45	82	6	77	8	68	11	72	12	81	6
46	83	6	78	8	68	9	69	13	83	5
47	83	7	78	8	69	9	65	19	84	5
48	82	7	78	8	70	11	67	19	84	4
49	83	6	79	8	69	11	69	14	85	4
50	83	6	79	9	71	10	72	11	84	5
51	83	5	79	9	71	10	75	9	85	6
52	84	5	80	8	73	11	76	9	85	5
53	84	5	79	8	76	12	75	9	86	5
54	84	4	79	8	76	12	73	12	83	10
55	84	4	80	7	77	12	76	8	83	11
56	84	4	80	7	79	9	77	8	85	6
57	85	4	80	7	77	9	77	5	83	8
58	85	4	80	7	79	9	77	8	85	6
59	86	4	81	6	78	8	75	8	87	3
60	86	4	81	6	77	9	73	8	88	4
61	86	4	80	6	76	9	76	6	85	8
62	86	4	81	6	76	9	78	5	84	11
63	86	5	81	6	77	8	77	7	86	7
64	87	5	82	6	77	9	77	9	87	6
65	87	4	82	7	77	10	76	8	88	4
66	87	5	82	7	79	10	78	8	88	4
67	87	5	82	6	79	10	79	10	89	3
68	87	4	82	6	79	10	78	8	90	3
69	87	4	82	6	80	10	76	8	90	4
70	87	5	82	6	80	9	76	7	90	3
71	87	5	82	6	79	10	76	9	90	3
72	87	5	83	6	78	12	78	7	90	3
73	87	5	83	6	78	12	80	7	87	9
74	87	5	83	5	80	11	80	6	86	12
75	88	5	83	6	79	11	82	5	87	7
76	88	5	83	6	81	8	81	5	88	5
77	88	5	83	5	83	8	79	5	88	6
78	89	4	83	6	83	9	78	7	89	5
79	89	4	83	6	82	9	78	7	89	6
80	89	4	84	5	82	8	77	7	89	6
81	89	4	85	6	83	8	78	8	89	6
82	89	3	85	6	84	8	79	7	89	6
83	89	5	85	5	85	8	78	6	89	7
84	90	5	85	5	85	7	75	6	87	10
85	89	5	85	5	84	6	73	9	88	8
86	89	5	85	4	84	7	74	10	90	4
87	90	4	85	5	83	6	76	8	89	5
88	89	5	85	5	82	6	78	10	89	4
89	90	4	85	5	83	6	81	13	89	5
90	90	4	85	6	84	6	81	12	88	6
91	90	4	85	5	84	7	82	9	88	6
92	90	4	86	4	84	8	80	8	88	8
93	91	4	86	4	84	7	80	9	87	9
94	90	4	86	5	85	8	79	10	88	7
95	90	4	86	4	86	7	79	11	86	13
96	90	3	86	4	85	7	82	9	88	9
97	89	4	85	4	86	7	85	10	92	3
98	90	4	85	4	86	7	86	13	92	3
99	90	4	85	4	86	7	84	15	93	4
100	90	3	85	4	85	7	81	12	92	3
101	90	3	86	4	85	7	81	9	90	5
102	90	4	86	5	85	8	80	12	89	9
103	90	4	87	5	86	7	79	10	87	14
104	91	4	87	5	87	6	78	9	89	10
105	90	4	87	5	87	5	80	8	91	4
106	91	4	87	4	88	5	81	9	91	5
107	91	4	87	5	87	6	83	9	93	4
108	92	4	87	5	87	6	82	8	92	4
109	92	3	87	5	86	6	79	8	90	6
110	92	3	86	5	87	6	78	7	89	12
111	91	4	87	5	87	7	78	6	90	7
112	91	5	87	5	87	7	77	7	92	4
113	91	4	87	5	88	7	77	7	92	4
114	91	4	87	5	88	6	80	9	91	4
115	91	3	87	5	88	7	81	10	90	5
116	90	3	87	5	88	7	82	13	90	6
117	90	3	87	4	88	8	82	10	91	5
118	91	4	87	5	88	7	81	9	93	4

	Running		Cylcing		Arm cranking		Kayaking		Canoeing	
	M	SD	M	SD	M	SD	M	SD	M	SD
119	91	4	87	5	88	7	78	10	93	4
120	91	4	88	5	87	6	79	9	91	5
121	91	4	88	5	86	7	81	8	90	7
122	90	4	87	5	86	7	81	7	92	4
123	90	4	86	5	86	8	79	8	91	6
124	90	4	87	5	86	9	80	7	89	11
125	90	4	87	4	87	9	78	9	90	8
126	91	4	87	4	88	8	78	10	92	3
127	91	4	88	4	87	7	79	13	90	9
128	91	4	88	4	87	7	80	12	90	9
129	91	4	88	4	87	7	81	11	91	7
130	91	4	88	5	86	7	80	7	89	11
131	91	4	88	5	86	8	81	7	89	12
132	91	4	88	5	85	8	83	9	91	6
133	91	4	88	5	86	7	82	12	92	4
134	91	3	88	4	86	7	83	10	90	10
135	91	4	88	4	86	7	82	8	88	13
136	91	3	88	4	86	8	81	10	90	8
137	91	4	88	4	85	7	81	10	92	6
138	91	4	87	4	84	7	81	10	91	9
139	92	4	88	4	85	8	81	9	91	9
140	91	4	88	4	85	9	82	9	93	4
141	92	4	88	3	85	9	81	8	92	5
142	91	4	89	4	86	9	80	9	94	3
143	91	4	89	4	86	9	80	10	93	3
144	91	4	89	4	87	9	79	9	92	5
145	92	5	89	4	88	10	78	12	91	9
146	91	5	88	4	87	10	81	13	91	10
147	92	4	88	5	87	9	85	10	92	7
148	92	4	88	5	86	8	83	10	91	8
149	92	4	88	4	86	8	82	10	91	11
150	92	4	89	3	85	8	84	9	91	8
151	92	4	90	3	85	9	86	8	92	5
152	92	3	90	4	85	9	87	10	93	5
153	92	4	90	4	85	9	85	10	93	4
154	93	4	89	5	86	10	85	9	92	6
155	93	4	89	5	86	9	83	7	91	10
156	93	4	89	5	85	8	82	10	92	7
157	92	4	89	4	85	8	79	11	92	4
158	92	4	89	3	85	8	78	11	91	9
159	92	3	90	3	86	8	79	12	92	7
160	92	3	90	3	87	8	82	12	92	4
161	92	3	89	3	87	8	82	13	91	9
162	92	4	90	3	87	8	79	12	91	11
163	92	4	90	2	88	8	79	13	92	11
164	92	4	90	3	88	8	81	12	94	6
165	92	4	90	4	88	7	81	12	94	5
166	92	3	90	4	89	7	80	12	92	11
167	92	3	90	3	88	7	80	12	93	9
168	92	4	90	3	89	7	81	11	92	10
169	92	4	90	3	87	7	81	10	92	13
170	92	5	90	3	86	8	81	8	93	6
171	93	5	90	3	86	8	82	9	96	3
172	93	4	91	4	86	8	86	9	95	5
173	93	4	91	4	87	6	84	10	93	6
174	93	4	91	4	88	6	84	9	92	8
175	92	3	91	4	88	7	84	8	90	12
176	92	4	91	4	88	7	85	8	89	14
177	92	3	91	4	88	8	84	7	91	10
178	92	4	91	4	87	8	82	11	90	13
179	92	4	92	3	87	7	82	7	92	9
180	93	4	93	3	86	7	84	8	94	6
181	93	4	93	4	86	7	85	9	94	3
182	93	4	92	3	86	6	85	8	93	5
183	92	5	92	3	86	6	80	10	92	7
184	92	4	92	3	87	7	80	11	92	8
185	92	3	92	4	87	8	78	10	92	8
186	93	3	92	4	87	8	80	10	89	16
187	94	4	92	4	87	9	80	8	92	8
188	94	4	92	3	87	8	82	10	95	3
189	94	3	92	3	86	7	81	9	95	3
190	93	4	92	3	87	6	82	9	96	3
191	93	3	93	3	88	5	82	7	96	3
192	93	3	93	3	88	5	81	9	96	4
193	93	3	93	2	87	5	80	13	94	7
194	93	3	93	2	87	5	79	13	93	9
195	94	3	93	2	87	5	79	12	93	7
196	94	3	92	2	88	5	77	11	91	12
197	94	4	93	3	89	5	80	10	92	10
198	94	3	93	4	88	5	81	10	94	6
199	93	3	93	3	88	5	81	11	92	11
200	93	3	93	3	87	6	80	10	90	17
201	94	3	93	3	88	6	80	13	92	11
202	94	3	93	3	88	5	82	11	94	5
203	94	3	93	3	89	5	83	12	92	11
204	93	3	93	3	89	5	83	10	93	8
205	94	4	93	3	87	7	82	10	94	6
206	94	3	94	3	87	7	82	11	92	10
207	94	4	93	3	84	8	83	9	93	6
208	93	4	93	4	85	6	83	10	96	3
209	93	3	93	3	87	5	82	10	94	4
210	92	3	94	3	87	5	80	11	93	5
211	92	3	94	3	89	5	80	9	92	7
212	92	3	95	3	89	5	81	8	93	6
213	93	3	94	3	90	5	81	10	94	7
214	93	4	94	3	89	6	80	11	96	5
215	93	4	93	3	89	7	80	13	97	2
216	94	4	94	3	88	8	81	12	97	3
217	94	4	94	4	89	8	81	12	94	11
218	94	4	95	4	90	7	80	10	93	9
219	94	3	94	2	91	6	82	10	93	4
220	94	3	94	3	90	6	82	11	91	9
221	93	3	94	4	91	5	83	12	93	9
222	93	3	94	3	91	5	81	13	94	8
223	93	3	94	3	91	5	80	13	93	12
224	94	3	94	4	91	3	79	11	92	14
225	93	3	95	3	91	4	80	12	94	6
226	93	4	95	3	92	5	81	9	94	6
227	93	3	95	2	92	4	80	11	95	4
228	93	4	96	2	92	4	78	10	93	9
229	93	3	96	2	93	5	78	11	92	12
230	94	2	95	2	93	4	78	12	91	12
231	94	3	94	2	92	5	77	13	93	9
232	93	4	95	3	91	5	77	13	93	8
233	92	4	95	2	91	4	79	12	93	8
234	92	4	95	4	93	5	81	12	94	7
235	93	4	95	4	93	4	82	12	94	7
236	92	4	95	3	93	5	80	11	95	5
237	92	4	95	3	92	5	81	12	92	10
238	92	4	95	4	91	5	81	10	92	10
239	92	4	94	4	92	6	82	10	95	4
240	92	5	93	6	93	6	85	9	94	6

Appendix 15: Blood Lactate Concentration at and above MLSS Workload

		Blood lactate [mM]						
		0	5	10	15	20	25	30
MLSS	M	1.35	4.42	5.27	5.47	5.52	5.29	5.44
	SD	0.27	0.65	0.72	0.80	0.76	0.71	0.71
>MLSS	M	1.44	5.45	6.72	7.29	7.70	8.05	8.59
	SD	0.32	1.67	1.98	1.92	1.34	1.49	1.46

Appendix 16: MLSS and MLSS workload

P-MLSS	MLSS
Watts	mM
99	5.49
104	4.88
101	4.75
76	6.33
149	5.54
124	4.77
130	5.04
115	6.64

Appendix 17: Workload at MLSS and Different Lactate Threshold

	MLSS	LT4	LT5	LT5.4
	Watt	Watt	Watt	Watt
M	112	104	113	115
SD	22	18	19	19

Eidesstattliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht.

Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich keine Unterstützungsleistungen von Personen erhalten.

Weitere Personen waren an der geistigen Herstellung der Arbeit nicht beteiligt. Insbesondere habe ich nicht die Hilfe eines Promotionsberaters in Anspruch genommen. Dritte haben von mir weder unmittelbar noch mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Die Arbeit wurde bisher weder im In- noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt und ist auch noch nicht veröffentlicht worden.

Leipzig, den 22. April 2014

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Curriculum Vitae

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Education

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Research

English Publication

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Kingdom, 2012 (*oral presentation*).

4. **Y. Li**, W. Zi, C. Cao, X. Chen, and U. Hartmann. Training of a Female World-Elite Rower in Pre-Olympic Year. *59th Annual Meeting of American College of Sport Medicine and 3rd World Congress on Exercise is Medicine*, San Francisco, United States of America, 2012 (*poster presentation*).

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Chinese Presentation

1. W. Zi, **Y. Li**, H. Yu, and X. Chen. Training Load and Performance - Study on Training Load of Chinese Elite Rower Zhang Xiuyun in Preparation for Beijing Olympics. 5th China Youth Sport Science Conference. 2008 (*invited oral presentation*).

Degree Thesis

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Experience

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