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Heart rate and blood lactate concentration analysis during a high level men's gymnastics competition

Monèm Jemni[1], Françoise Friemel[1], Jean-Michel Lechevalier[2], Michel Origas[3]

1. A.D.D.M.S. 94: Centre Départemental de Médecine du Sport. 2, Rue Tirard, 94 000 Créteil. France.
2. Laboratoire de biomécanique et de physiologie. Institut National du Sport et de l'Education Physique. 11, Avenue du Tremblay, 75012, Paris. France.
3. Département de formation des cadres. Institut National du Sport et de l'Education Physique. 11, Avenue du Tremblay, 75012, Paris. France.

Abstract

Seven 18-year-old volunteer French international elite gymnasts participated in a simulation of a competition. Heart rate (HR) was measured by a continuos method and blood lactate concentration (BL) was measured before and 2, 5 and 10 minutes after each gymnastics event. Mean duration of floor, pommel horse, rings, horizontal bars and fix bar exercises was 34.70 $\pm$ 5.00 s, except vaulting which lasted 5.16 $\pm$ 0.40 s. High performance gymnasts required a very high HR (179.49 ± 10.39 $b.min^{-1}$) during a very short time. Each event required a specific heart rate range. Mean peak BL value was 5.07 $mmol.1^{-1}$ on five apparatuses. Vault was significantly less than those of the other exercises. HR and BL values differed between events.

We concluded that vaulting effort provided a recovery effect on the following events and we suppose that an active recovery is useful between events.

Key words:

bioenergetics - physical fitness - recovery - aerobic - anaerobic

Introduction

To attain a high performance level, gymnasts begin practising at an early age. They must reach a very high level of strength, flexibility and coordination to perform the variety of complex acrobatic movements. By the 1960s, many authors confirmed that gymnasts were characterised by a low maximal aerobic power and a high strength quality (26, 15, 28, 20). Many others studied the impact of this sport or the rhythmic sportive gymnastics on body and bone development in young females (1, 2, 3, 7, 9, 11, 13, 14, 19, 22, 23). Most of these studies confirmed that gymnastics practice was associated with a late bone development and an ectomorphic tendency, especially in female gymnasts. Rhythmic and female gymnasts have been studied for a long time (1, 2, 13, 14) but no one has explored boys gymnastics' physiological responses since Montpetit in 1976 (20, 21). Boys HR response has not been studied since that date, whereas lactate production has never been studied. Authors who investigated gymnastic physiological responses never studied competitive routines, especially not the vaulting exercise because of its short duration (4, 7, 11, 20, 21, 27). Energy expenditure could not be compared to that of running at 13 $km.h^{-1}$ as it had been considered since the 1970s (20). These disciplines are completely different: gymnastics is a technical sport, whereas running is a cyclical one. So, efforts are not the same, physiological and psychological requirements are also different. The multitude of gymnastics situations and

events as well as the variety of muscular contractions could be the reason for few investigations.
Gymnastic training is based on the repetition of movements, so gymnasts practice for long period sessions. I have observed that coaches seldom ask themselves about the effectiveness of the repetitions or the quality of recovery.
The aim of this study was to analyse HR and BL from one apparatus to another during the six events (Floor, Pommel horse, Rings, Vault, Parallel bars and Horizontal bar) of men's gymnastics competition. A secondary purpose was to examine the physiological effects of performing a series of gymnastics events.

Methods

Subjects

Seven male volunteer gymnasts of the French international gymnastic team, aged 18.43 ± 1.13 years old participated in the study. They trained two hour long sessions per day, 6 days per week. All subjects and parents were informed of the nature and possible inconveniences associated with the experiment. Informed consent was obtained from all participants.
Their physiologic characteristics are shown in table 1. Their ς O_2 max was measured using a standard maximal treadmill test. Their skinfold thickness were measured according to Durnin and Rahaman (10). Skeletal ages were determined according to Risser method using a radiological exam of the pelvis (26). This test was used to assess skeletal maturity (table 1).

Protocol

The test was a simulation of a gymnastics competition. Judges, timekeepers, doctors, coaches and spectators attended the competition session to simulate real conditions. Two competition sessions were organised. The first was composed of four gymnasts and the second was composed of three gymnasts. Two physiological parameters were evaluated: HR and BL. The test took place in a gymnasium a week after the French National Cup. The session began by 15 minutes of general warm-up, followed by a specific warm-up of 30 minutes. The competition was composed of 6 events. Olympic rotation order was used to pass from one apparatus to another. Competition began with floor exercises, followed by pommel horse, rings, vaulting, parallel bars and horizontal bar.
Each of the six competition routines were separated by 10 minutes of recovery. Recovery time in official international competition is similar. Three blood samples (25 μl) were taken from a hyperaemic earlobe 2, 5 and 10 min after each event. A ten minute recovery time was also provided at the end of the warm-up period. A three minute specific warm-up time was provided before each event as per FIG rules (International Gymnastics Federation). Each gymnast's performance was judged by two judges. Programs were free but technical composition did not vary between gymnasts. Each gymnast was controlled by two timekeepers, who measured real effort time at each event (table 2) and told the doctors when to sample blood from their gymnast. Gymnasts were required to perform the next event just after having their blood samples taken at 10 recovery minute.

Heart rate was continuously monitored by a Bauman Sport-tester BHL 6000. Minimal, maximal and average HRs were determined for each event. The determination of blood lactate concentration was performed by a micro-enzymatic method with a *Microzym L-analyser.*

Statistical analyses

The means $\pm$ standard deviations were calculated for all data. Comparisons between event HR values as well as BL data were made using one-way analysis of variance (ANOVA) with repeated measures. When significant mean differences were found ($p < 0.05$) a PLSD *Fisher* post-hoc test was applied.

Results

Physical characteristics

The means and standard deviations of physical characteristics of the subjects are shown in Table 1. The maturity test of Risser (24) showed that skeletal age was less than chronological age. This group of gymnasts was about 6 months late-maturing.

Table 1 Physiologic characteristics of the gymnasts

	Age year	B. mass kg	Height cm	B. fat (%) 4 skinfolds	Risser level	ς O_2 max $ml.kg^{-1}.min^{-1}$
mean	18.43	66.11	171.57	8.85	4.25	52.62
SD	1.13	3.82	6.21	1.29	0.42	3.02

B = body ; Risser level: radiological exam of the pelvis

Simulated competition

Work times measured at each event are shown in Table 2. The shortest one was vaulting (5.16 $\pm$ 0.41 s) and the longest was the floor exercises (60.90 $\pm$ 3.44 s). Pommel horse, rings, parallel bars and horizontal bar lasted approximately 35 s.

Table 2 Duration of each event

	Mean (s)	SD
Floor	60.90	3.44
Pommel	30.47	4.49
Rings	40.68	5.05
Vaulting	5.16	0.41
Parallel bars	31.14	6.22
Horizontal b.	36.50	6.59

Mean and SD HR are shown in Table 3. Gymnastics competition events induced very high HR values during a short time, as can be seen from Table 4. Only 16.31 % of these values were between 180 and 190 $b.min^{-1}$ (table 4). Most recorded values were between 158 and 170 $b.min^{-1}$. Nevertheless, there were differences between apparatus requirements. Table 4 shows that the most required HR range in floor exercises was that between 171 and 179 $b.min^{-1}$. Gymnasts used this range about 34.44 % of the performance time. The same range was required approximately 26 % of the time in horizontal bar. HR never exceeded 179 $b.min^{-1}$ in vaulting event. Mean vault values were significantly less than those of the other exercises ($p < 0.05$) (table 3). After a 10-minute recovery period, HRs were usually greater than their rest values (table 3).

Table 3 Mean values (± SD) of maximal, average, and after 10 recovery minute heart rate

	Heart rate ($b.min^{-1}$)		
	Mean	maximal	10 recovery min
Floor	173.29 ± 7.34	186.00 ± 11.33	105.71 ± 10.83
Pommel	166.43 ± 11.53	184.57 ± 10.63	110.43 ± 4.43
Rings	.	.	103.00 ± 10.03
Vaulting	148.86 ± 15.56*	161.71 ± 14.21*	101.57 ± 9.03
Parallel bars	170.00 ± 9.86	180.17 ± 10.63	102.00 ± 5.92
Horizontal bar	172.86 ± 10.61	185.00 ± 9.06	101.57 ± 9.48
Mean	*166.29*	*179.49*	*104.05*
SD	*10.12*	*10.19*	*3.49*

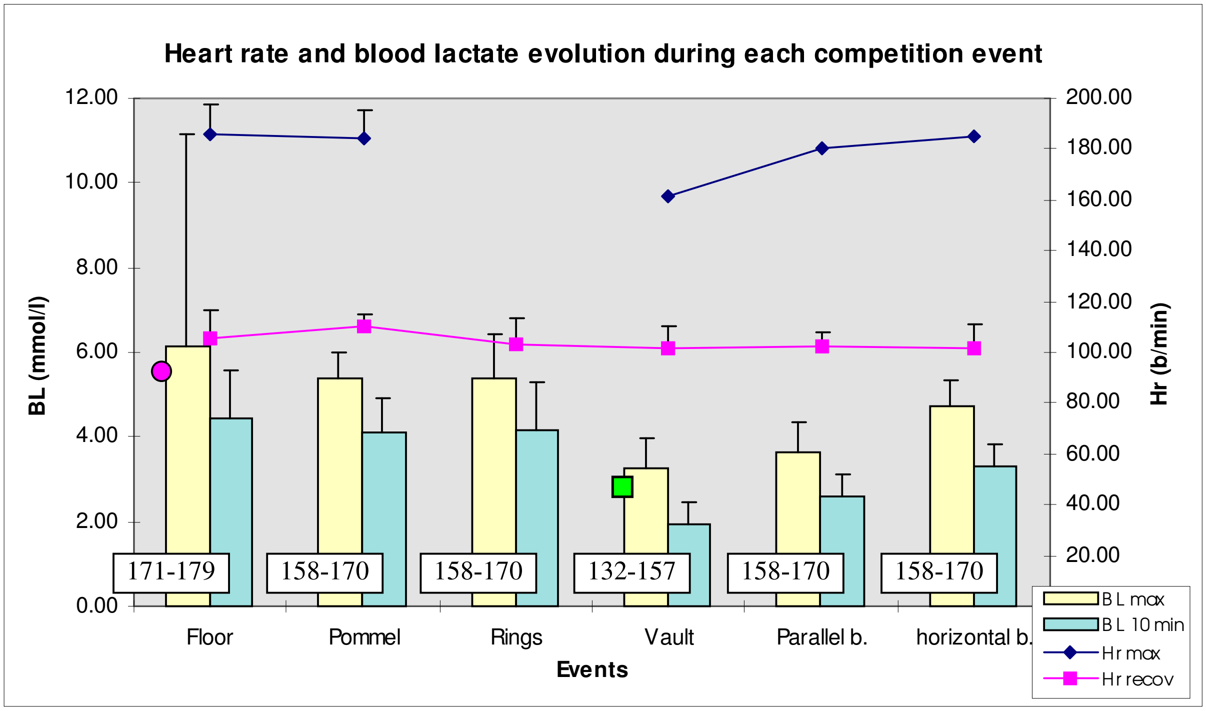
* significantly different ($p < 0.05$)
Remark. rings heart rates were not studied because of artefacts found in the records

The mean maximum BL of all six apparatuses was 4.77 ± 1.11 $mmol.1^{-1}$. Peak level BL appeared at the second minute after each event, except after the pommel horse, where it was slightly higher at the fifth minute but not statistically significant ($p < 0.05$). BL varied from one apparatus to another (fig 1). The highest value was observed during the floor exercise (6.13 ± 1.00 $mmol.1^{-1}$). The lowest value was at the vaulting event (3.27 ± 0.68 $mmol.1^{-1}$). Between these two values were - in decreasing order - those of pommel horse, rings, horizontal bar and parallel bars. Statistical comparisons showed that vaulting values were significantly less than those of the other exercises. On the other hand, floor exercises values were significantly higher than those of vaulting, parallel bars and the horizontal bar. At the end of the recovery period, BL was usually higher than its rest value. The 10-minute recovery' s BL value was considered the starting one for the next apparatus (Fig 1). Maximal BL decreased progressively until the vaulting event, then increased during parallel bars and horizontal bar series.

Discussion

Comparing biometric characteristics of our group to those of average level gymnasts of a similar age group (approximately 18 years old) (21) (27), our data showed nearly the same height, the same weight and the same percentage of body fat. So we can say that biometric characteristics are not requisite to success at a higher level. On the other hand, the comparison with the male gymnasts who participated in the Olympic Games of Tokyo 1964 (20) revealed that our group was taller, heavier and younger. We observed the same thing by comparing with the French men aerobic team of 1996 (12).

Our male international gymnasts have a low ς O_2 max. Experimental methods used to investigate aerobic and anaerobic metabolisms were described in recent papers (16, 18). The overage ς O_2 max is comparable with that of females (4, 7, 19, 20, 27).



: Significantly higher than vaulting, parallel bars and horizontal bar.

: Significantly less than the other events.

...-... : Most used heart rate range at each event.

The six months late maturity might be the reason for the low average lactate value; less Phosphofructokinase activity reduces the glycolysis possibilities.

Table 4 Required heart rate ranges by apparatus and the time during they have been recorded.

	% HR between 100 - 131 b.min^{-1}	time min	% HR between 132 - 157 b.min^{-1}	time min	% HR between 158 - 170 b.min^{-1}	time min	% HR between 171 - 179 b.min^{-1}	time min	% HR b 180 - b.m
Floor	0.00	0.00	7.26	0.06	30.93	0.25	34.44	0.28	20.
Pommel	7.37	0.07	16.16	0.12	32.44	0.17	15.03	0.12	20.
Vaulting	19.17	0.07	44.97	0.18	22.54	0.04	13.31	0.03	0.(
Parallel bar	0.00	0.00	15.56	0.09	26.63	0.22	18.56	0.09	19.
Horizontal b	0.00	0.00	12.69	0.12	29.89	0.33	26.00	0.19	22.
Mean	5.31	0.03	19.33	0.11	28.49	0.20	21.47	0.14	16.
SD	8.38	0.04	14.76	0.04	3.95	0.11	8.74	0.10	9.

HR = Heart rate

Montpetit (20) supposed that lactate production during gymnastic routines was negligible. Our results don' t confirm this, seeing that BL mean values were between 3.27 $\pm$ 0.68 and 6.13 $\pm$ 1.00 mmol.1^{-1}. So the average BL value of all cumulated events was over the Kindermann threshold (4.77 $\pm$ 1.11 mmol.1^{-1}, or 5.07 mmol.1^{-1} excluding vault) in spite of the late maturity observed in this group of gymnasts. (Kindermann threshold is an index (4 mmol.1^{-1}) describing that the rate of lactate appearance is more important than its removal. It indicates the moment when anaerobic metabolism is more required than the aerobic one) (17).

However, our values seem to be less than those found in rhythmic gymnasts (1), women gymnasts (19) and aerobic sport athletes after they perform their competitive routines (25), or in top level swimmers performing freestyle 50, 100 and 200 m (6). It appears that energetic profile differed in each one of these sports.
Except in the vault event, it appears that the greatest demands for power in gymnastics is provided from the glycolysis metabolism except vault.
Montpetit (20) concluded that oxygen consumption was small (approximately 8 $ml.kg^{-1}.min^{-1}$) due to the short duration of the exercises (20 to 30 s). Nevertheless, the main part of the energy production is assured by ATP-PC degradation.

As can be seen in Table 5, Dl, D2, D3, D4, D5 and D6 represent the BL difference between the peak and after 10 minutes recovery at each event. These differences give an idea about the metabolic recovery after each event. The greatest difference was found after the floor exercise. It was followed in decreasing order by horizontal bar, pommel and vaulting, rings and parallel bars. But we should remember that the effort and duration differ between the events. A significant difference was only observed between Dl and D5, in other words, between the recovery times after floor and parallel bars exercises. After the parallel bars exercise, gymnasts do not recover as well as after the floor routines in this rotation order.

Table **5** Blood lactate production and consumption a long the competition

D ($mmol.l^{-1}$)		M ($mmol.l^{-1}$)	
D1 (floor)	1.67	M1 (rest - floor)	5.19
D2 (pommel)	1.37	M 2 (floor-pommel)	1.00
D3 (rings)	1.24	M 3 (pommel-rings)	1.31
D4 (vault)	1.31	M 4 (rings-vault)	-0.89
D5 (P. bars)	1.03	M 5 (vault-P. bars)	1.67
D6 (H. bar)	1.43	M 6 (P. bars-H. bar)	2.13

D = Difference between peak blood lactate and after 10 recovery minute per each apparatus;
M = Blood lactate difference before and after each apparatus.

MI, M2, M3, M4 and M5 represent the difference between BL before and after each apparatus (table 5). They give an idea about metabolic requirement at each apparatus. BL increased after each event except in vaulting, where it decreased. So we note that these differences were positive for all apparatuses except vaulting, where it was negative. BL difference increased between pommel horse and rings events, then it decreased during vaulting and finally it increased during parallel and horizontal bar. It decreased from the end of the rings exercise to the end of the vaulting recovery period. A significant difference was only observed comparing M4 to the other differences. Therefore the difference between rings and vaulting BL was smaller than the other differences. During the vaulting exercise, mean BL decreased from 4.16 ± 1.13 to 3.27 ± 0.68 $mmol.1^{-1}$(M4 = -0.89). This difference was statistically significant ($p < 0.05$). This means that lactic acid was consumed after the rings series. In other words, gymnasts continued to recover during the rest period between the end of the rings series until the beginning of the parallel bars exercise. So, effort performed during the specific warm-up and the vaulting competition induced a diminution in BL (4 vaults separated by approximately 1 min 30 s). So we can say that vaulting exercise provided a recovery effect for the following event. The same phenomenon was observed in sprint swimmers using an active recovery (8).

Two potential hypotheses can be proposed from the results this investigation found:

1- vaulting event is more alactic than lactic. Lactate dissipation exceeds its accumulation in this exercise;
2- with a sufficiently long recovery period, a gymnast can perform intense and short efforts (4 to 6 seconds) without any change in BL level.
We noted also that HR values were not high in pommel horse. This result seems to be remarkable, because this event used especially the arms; they must carry the body-weight from one part of the apparatus to another while performing continuously movements and combinations; HR would be higher than during an exercise done with the legs at the same power (5).
Some authors have tried to explain the high heart rate by physiological mechanisms: Vander (29) concluded that this phenomenon concern not only central blood circulation but also the peripheral nervous system. It seems that information from the central nervous system stimulates the vaso-dilator sympathic' axis which induces a vaso-dilatation of the muscular arteries and modifications on heart behaviour: increment of the general and local blood flow as well as heart rate. Otherwise, the high HRs noticed just before the beginning of each event were supported by the increment of the adrenal hormones.
As we did not observe a steady state of HR during the gymnastic exercises, it is difficult to interpret their energetic significance. We cannot estimate the energetic cost from the relation of HR to oxygen uptake as measured during a treadmill test. Training evaluation through heart rate should consider this fact to avoid any misinterpretation, especially if we cannot eliminate the psychological stress effect. Otherwise, mean HR may give a better idea about the event intensity.

Conclusion

While heart rate response was strong during gymnastic exercises, blood lactate concentration remained not negligible seeing mean overage above lactate threshold. The lactate concentration differed between apparatuses. Vaulting lactate value, as well as its heart rate, were significantly smaller than those of the other exercises. Floor routines induced the highest lactate production, followed in decreasing order by 1) rings and pommel horse, 2) horizontal bar and 3) parallel bars.
We concluded that vaulting effort provided a recovery effect on the following events.

Practical applications

The data here elucidate the metabolic requirement through the course of a gymnastics competition and show the differences between events. The anaerobic requirement is very important in four events contrary to what it used to be considered. The study shows also a recovery effect of one exercise (vault) on another. By knowing such indices, coaches could prescribe individual training programs at each phase of the season such as the competitive one in which gymnasts usually have to repeat their six events two to five times in one session. The recovery effect of one exercise on another highlighted in this study may cause coaches to think also about making the recovery between special events active rather than passive. This has been done in many other sports.

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Corresponding Author:
Monèm Jemni
Address: A.D.D.M.S. 94: Centre Départemental de Médecine du Sport. 2, Rue Tirard, 94000, Créteil. France.
Tel 0-1 48 99 16 16. Fax: 0-1 48 99 18 07.
E-mail: monemj@hotmail.com