Br J Sp Med 1991; **25**(1)

Effect of pre-exercise protein ingestion upon $\dot{V}O_2$, *R* and perceived exertion during treadmill running

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The study investigated the effect of pre-exercise protein ingestion upon the oxygen consumption ($\dot{V}O_2$), respiratory exchange ratio (*R*) and perceived exertion (PE) of athletes during treadmill running at intensities of approximately 60, 80, 90 and 100% of their $\dot{V}O_{2\,max}$. Seventeen female athletes aged between 17 and 22 years participated in the study. Subjects completed six assessment sessions, each being preceeded by one of the following dietary regimens: a protein solution ingested 3 h before assessment (P3), a protein solution ingested 1 h before assessment (P1) and the ingestion of water 1–3 h before assessment (B). The subjects' $\dot{V}O_2$, *R* and PE were measured at all exercise intensities using standardized procedures. The results showed that P1 produced significantly higher values for $\dot{V}O_2$ ($P < 0.05$) at all exercise intensities and was associated with an increased PE ($P < 0.01$). The findings could have implications for athletes when considering the composition of their pre-exercise meal, especially if performing in activities which require the participants to exercise close to or at their $\dot{V}O_{2\,max}$.

Keywords: Thermic effect, protein, pre-exercise food

In resting individuals, recently ingested food has been found to induce a substantial increase in metabolic rate as measured by oxygen consumption[1,2]. This is referred to as the specific dynamic action (SDA) of the food or its thermic effect. According to Suttie[3] the biochemical basis for this increase is not clearly understood; however, most authors agree that it is largely due to the metabolism of foods by the liver, while the processes of digestion and absorption have a relatively small effect. Research into the thermic effects of pre-exercise food upon normal and obese individuals during exercise[4–8] indicates that an elevated oxygen consumption ($\dot{V}O_2$) caused by the thermic effect of the food occurs during exercise as well as at rest. The research by Zahorska-Markiewicz[5] also concluded that in non-obese subjects the measured thermic effect was substantially larger during exercise than at rest. In addition, it was found that the $\dot{V}O_{2\,max}$ values of subjects are not altered after ingestion of food[7].

Despite the recent research into the thermic effect of food on normal and obese individuals, relatively little research has been conducted using 'athletic' subjects working at relatively high exercise intensities. Some indication that pre-exercise food could affect athletic performance was reported by Bird and Hay[9] who observed elevated heart rates in students of physical education during submaximal forms of exercise shortly after ingestion of protein and glucose. For athletic individuals, slight changes in metabolic rate and $\dot{V}O_2$ whilst exercising could have substantial effects upon their performance. For instance, a conflict between the exercising muscles and organs such as the liver for the available oxygen during exercise could result in the muscles receiving a reduced oxygen supply. It was the aim of this study to investigate the effects of pre-exercise food upon the $\dot{V}O_2$, respiratory exchange ratio (*R*) and the perceived exertion (PE) of athletic individuals during submaximal and maximal forms of exercise.

Materials and methods

Seventeen female athletes aged between 17 and 22 years volunteered to participate in the study. All were non-smokers and familiar with maximal forms of exercise. The group included college, club, county and national standard athletes whose weights ranged from 49 to 73 kg. Each subject underwent three familiarization sessions which were used to assess their $\dot{V}O_{2\,max}$, determine appropriate running speeds to be used during the investigation and enable the subjects to become familiar with the test protocol. Each subject then had six assessment sessions.

Diet

Before each assessment session subjects were requested to fast overnight (12 h) and were then given one of the following pre-exercise meals.

1. A protein solution ingested 1 h before assessment (P1)
2. A protein solution ingested 3 h before assessment (P3)
3. A minimum of 400 ml of water taken between 1 and 3 h before assessment (B)

Throughout the fasting and pre-exercise period subjects were permitted to drink as much water as they desired. The protein solution consisted of 0.4 g kg^{-1} body weight of Healthlife Sport (Baildon, UK) 90% protein powder which was mixed with

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0306-3674/91/010026-05

approximately 400 ml of water. Protein was specifically selected as the major constitutent of the pre-exercise meal since it is widely reported to have the most substantial thermic effect[1,2]. Each dietary regimen was administered on two occasions and the tests were performed in a random order with subjects always being assessed during the morning at approximately the same time to avoid any diurnal effects[10,11]. A minimum 48 h recovery time was given between each assessment and subjects were not assessed on days when they considered that their menstrual cycle would affect their performance. All subjects completed the six assessments within a 5-week period with the majority completing in less than 15 days. Throughout the duration of the investigation subjects were encouraged to maintain their normal diet and within the investigation no subject altered her weight by more than 2 kg.

Exercise

At the beginning of each assessment session subjects underwent a thorough warm-up which included running on the treadmill (zero per cent gradient) for a minimum of 5 min at self-selected speeds; this was then followed by a series of static stretching exercises. This type, duration and intensity of warm-up was considered necessary to prepare the athletes for the assessment both physically and mentally and also to reduce the risk of injury. The test protocol required the subjects to run on a motorized treadmill (E10 Powerjog Sport Engineering, Birmingham, UK) which was set at a 10% gradient throughout the assessment. At a lesser gradient a faster running speed would have been required to achieve $\dot{V}O_{2\,max}$ and this could have resulted in the athletes exceeding their 'safe' running speed on the treadmill[12]. Alternatively, a gradient in excess of 10% would have altered the running mechanics to such an extent that the assessment would not have been a reliable measure of $\dot{V}O_{2\,max}$. Athletes' running speeds were determined by the speed of the treadmill and could be set with an accuracy of 0.1 km h^{-1}. This was, therefore, deemed more reliable than other methods of assessment such as a cycle ergometer where the subject's actual speed could fluctuate around the predetermined speed.

Data collection

During the assessment, subjects were required to run for 2 min at speeds corresponding to approximately 60, 80 and 90% of that required to produce their $\dot{V}O_{2\,max}$. They then proceeded to run for another 1 min at a speed which was close to that required for them to attain their $\dot{V}O_{2\,max}$ but which they could attain each time. This final minute was, therefore, referred to as the 100% exercise intensity but was in reality just below their absolute maximum. The test was continuous and lasted for a total of 7 min. During the final minute of each submaximal exercise intensity and the 1 min 100% exercise intensity, expired air samples were collected for 60 s in 200 l Douglas bags (W.E. Collins, MS, USA) using low resistance SRI (Scientific Research Instruments, Edenbridge, UK) mouthpieces and triple head valves. Expired air samples were analysed using separate oxygen (Sybron/Taylor Servomex, 570A, Crowborough, E. Sussex, UK) and carbon dioxide (Analytical Development Company, Hoddesdon, UK) analysers which had been calibrated using certified gas mixtures (British Oxygen Company, London SW19, UK) and the volume of expired air was assessed using an SRI dry gas meter. Additional data, including the temperature and barometric pressure, were also recorded and used in the calculations. The $\dot{V}O_2$ and R values for each exercise intensity were then calculated using a BBC microcomputer (Acorn Computers, UK) program based upon the calculations given by MacDougall *et al.*[12]. Thus, the procedures used complied with the recommendations of Thoden *et al.*[13] and McConnell[14]. The $\dot{V}O_2$ and R values obtained for each dietary regimen were then compared using analysis of variance tests, with a separate analysis being performed for each of the four exercise intensities.

Throughout the assessment the subjects' perceived exertions were monitored 30 s into each submaximal exercise intensity using the Borg scale[15]. On completion of each test, subjects were asked to rate the final exercise intensity according to the following 1 to 5 scale which was devised for the investigation:

5 Absolute maximum/overstretched
4 Tough maximum
3 Maximum
2 Tolerable maximum
1 Comfortable maximum

Upon completion of all six assessment sessions each dietary regimen was then ranked according to each subject's level of perceived exertion. A value of 1 was allocated to the regimen which was perceived by the subject to make the assessment session most difficult, a value of 2 to what was perceived to be the next most difficult regimen and a value of 3 to the regimen which resulted in the lowest level of perceived exertion. Where subjects did not perceive any significant difference in the difficulty of the sessions, the dietary regimens were ranked equally with each being allocated the mean of the rank scores. This data was then analysed using a Freidman two-way analysis of variance[16].

Results

Each subject's mean $\dot{V}O_2$ and R values at each workload were calculated from the two replicate runs and the data analysed using two-way analysis of variance tests. Statistically significant differences between dietary regimens were then further analysed using 'least significant difference' tests. The coefficient of variance for the measurement techniques at exercise intensities of 60, 80, 90 and 100% were 4.71, 2.51, 2.89 and 2.85% for the $\dot{V}O_2$ measurements and 4.72, 4.02, 3.94 and 3.89% for the R values respectively. A summary of the data is presented in *Tables 1* and *2*. The perceived exertion data is summarized in *Table 3*.

Table 1. Oxygen consumption (ml kg^{-1} min^{-1}) relaxed to exercise and diet (mean of two replicate runs)

Subject	*Exercise intensity (%)*	*Dietary regimen*		
		B	*P1*	*P3*
1	60	42.4	44.9	43.1
	80	52.1	53.1	52.8
	90	56.6	58.1	55.6
	100	58.6	60.9	57.4
2	60	43.3	45.5	43.2
	80	53.0	58.7	52.8
	90	58.7	61.4	56.6
	100	59.6	63.2	58.0
3	60	45.2	44.9	46.0
	80	54.7	55.8	54.5
	90	60.3	61.4	59.3
	100	61.1	63.9	59.3
4	60	40.2	44.7	42.1
	80	49.0	53.0	51.5
	90	55.0	58.5	56.3
	100	56.8	57.5	57.5
5	60	28.0	30.1	29.0
	80	40.7	43.1	41.7
	90	43.7	47.7	44.9
	100	46.1	49.2	46.5
6	60	33.3	38.3	34.6
	80	40.7	42.7	41.0
	90	43.4	47.5	45.7
	100	45.9	48.2	46.9
7	60	37.2	37.7	35.9
	80	45.2	45.1	42.5
	90	48.6	49.4	48.6
	100	51.2	52.7	52.9
8	60	39.4	40.3	41.6
	80	48.9	48.7	49.9
	90	52.0	53.4	53.5
	100	56.1	56.7	56.0
9	60	35.0	37.5	35.4
	80	45.4	45.9	41.2
	90	50.0	50.9	49.0
	100	52.0	56.3	52.1
10	60	34.9	32.5	31.0
	80	43.8	44.1	43.2
	90	48.4	47.6	47.7
	100	51.1	50.3	51.0
11	60	35.4	34.9	34.9
	80	41.5	42.2	42.4
	90	42.6	44.6	45.9
	100	47.4	47.5	48.1
12	60	30.7	32.2	30.9
	80	43.1	41.7	42.4
	90	46.9	47.0	48.5
	100	48.8	48.3	50.3
13	60	34.2	35.0	35.7
	80	43.4	43.0	44.2
	90	46.8	46.5	46.0
	100	47.6	47.8	48.3
14	60	32.7	30.3	29.4
	80	44.5	43.6	44.0
	90	49.6	49.4	50.4
	100	50.6	49.7	52.6
15	60	34.9	36.2	35.6
	80	44.7	44.9	43.9
	90	48.8	50.0	47.6
	100	49.5	50.7	53.3
16	60	28.9	30.2	30.3
	80	33.9	41.3	41.7
	90	43.4	46.3	43.6
	100	44.2	46.2	43.9
17	60	28.8	30.9	29.4
	80	40.2	40.5	40.5
	90	42.0	42.5	43.2
	100	42.7	42.7	43.6
Group mean (s.d.)	60	35.6 (5.16)	36.8 (5.63)	35.8 (5.56)
	80	45.0 (4.63)	46.3 (4.91)	45.3 (4.65)
	90	49.2 (5.68)	50.7 (5.81)	49.5 (4.95)
	100	51.1 (5.54)	52.5 (6.20)	51.6 (4.94)
F ratio for dietary regimens	60	5.499 ($P < 0.01$)		
	80	3.197 ($P < 0.05$)		
	90	8.375 ($P < 0.01$)		
	100	4.232 ($P < 0.05$)		

B, P1, P3: see text for definitions

Discussion and conclusions

At all exercise intensities higher mean $\dot{V}O_2$ values were recorded following dietary regimen P1. These differences were statistically significant between regimens P1 and B with regimen P3 producing intermediate values. The mean difference in $\dot{V}O_2$ between regimens P1 and B were 1.20, 1.30, 1.50 and 1.40 ml kg^{-1} min^{-1} at exercise intensities 60, 80, 90 and 100% respectively. These values represent an increase in $\dot{V}O_2$ following the ingestion of protein of approximately 3.4, 2.9, 3.0 and 2.7% respectively. This elevated $\dot{V}O_2$, which may be attributed to the thermic effect of the recently ingested food, is, therefore, slightly less than those reported by Welle[6] and Zahorska-Markiewicz[5] but may be related to the size of the meal ingested, which was smaller in this investigation. The results of this investigation showed no significant difference in the magnitude of the thermic effect at different exercise intensities, and, therefore, agree with the findings of Segal *et al.*[7] The intermediate values for P3 would imply that whilst a small thermic effect could still be recorded after 3 h, the peak thermic effect of the protein occurred within 3 h of its ingestion.

Assessment of the perceived exertion data indicates that the athletes found the P1 trials significantly ($P < 0.01$) more difficult than the B trials. These findings could suggest that despite the elevated $\dot{V}O_2$ following the ingestion of the protein the additional

Table 2. Expiratory exchange ratio related to exercise and diet (mean of two replicate runs)

Subject	*Exercise intensity (%)*	*Dietary regimen*		
		B	*P1*	*P3*
1	60	0.81	0.82	0.82
	80	0.94	0.92	0.93
	90	1.01	0.97	1.00
	100	1.00	0.99	0.98
2	60	0.85	0.84	0.81
	80	1.00	0.96	0.95
	90	1.04	1.00	0.99
	100	1.04	0.97	1.01
3	60	0.83	0.86	0.84
	80	1.01	0.99	0.99
	90	1.05	1.03	1.01
	100	1.07	1.02	1.05
4	60	0.73	0.81	0.78
	80	0.95	0.98	0.98
	90	1.04	1.03	1.01
	100	1.09	1.07	1.01
5	60	0.93	0.85	0.86
	80	0.97	0.95	0.96
	90	1.01	1.00	0.98
	100	1.03	1.01	0.97
6	60	0.77	0.76	0.80
	80	0.99	0.95	0.95
	90	0.95	0.98	0.96
	100	0.97	0.99	0.95
7	60	0.79	0.80	0.82
	80	0.99	0.94	0.96
	90	1.02	0.99	1.03
	100	1.07	1.01	1.05
8	60	0.75	0.75	0.77
	80	0.91	1.01	0.90
	90	1.03	1.08	0.98
	100	1.09	1.09	1.01
9	60	0.84	0.76	0.75
	80	0.95	0.87	0.84
	90	0.98	0.90	0.92
	100	1.03	0.95	0.93
10	60	0.74	0.79	0.76
	80	0.90	1.00	0.99
	90	0.91	0.98	0.99
	100	0.92	1.04	0.99
11	60	0.83	0.88	0.84
	80	0.98	1.00	0.99
	90	1.05	1.07	1.08
	100	1.03	1.07	1.05
12	60	0.78	0.77	0.76
	80	0.91	0.92	0.89
	90	0.99	0.97	0.96
	100	1.01	0.97	1.00
13	60	0.76	0.82	0.77
	80	0.98	1.01	0.96
	90	1.09	1.15	1.08
	100	1.14	1.15	1.13
14	60	0.82	0.82	0.79
	80	0.90	0.93	0.89
	90	0.99	1.01	0.98
	100	1.03	1.00	1.00
15	60	0.76	0.75	0.75
	80	0.84	0.79	0.81
	90	0.91	0.84	0.89
	100	0.92	0.86	0.91
16	60	0.73	0.75	0.72
	80	0.85	0.87	0.86
	90	0.87	0.89	0.88
	100	0.90	0.95	0.94
17	60	0.75	0.75	0.79
	80	0.85	0.82	0.87
	90	0.93	0.86	0.87
	100	0.95	0.94	0.91
Group mean (s.d.)	60	0.79 (0.053)	0.80 (0.044)	0.79 (0.038)
	80	0.94 (0.054)	0.94 (0.065)	0.92 (0.057)
	90	0.99 (0.061)	0.99 (0.080)	0.98 (0.059)
	100	1.02 (0.072)	1.00 (0.067)	0.99 (0.058)
F ratio for dietary regimens	60	0.532 (n.s.)		
	80	0.825 (n.s.)		
	90	1.248 (n.s.)		
	100	2.419 (n.s.)		

B, P1, P3: see text for definitions

oxygen was not being used by the exercising muscles. Such a hypothesis would be supported by the findings of Segal *et al.*[7] who suggested that the $\dot{V}O_{2\,max}$ of subjects was not increased by the recent ingestion of food. Therefore, it may be speculated that any increase in the demand for oxygen by the body could result in a conflict for the available oxygen between the exercising muscles and other organs involved in the metabolism of the recently ingested food. Thus the availability of oxygen for the exercising muscles could be reduced. Such deprivation would result in an increased dependency upon anaerobic metabolism and hence an elevated perceived exertion at each exercise intensity. It may, therefore, be suggested that recently ingested protein could affect oxygen utilization in such a way as to be detrimental to the performance of the athlete.

Analysis of the *R* data revealed no significant difference between the B and P1 trials at any exercise intensity.

Table 3. Perceived exertion related to diet and Friedman two-way analysis of variance ($n = 17$ subjects)

Dietary regimen	B	P1	P3
Mean ranked perceived exertion	2.56	1.47	1.97
χ_R^2 (when corrected for ties)	$= 14.596$ ($P < 0.01$)		

B, P1, P3: see text for definitions

The results would, therefore, suggest that the recent ingestion of protein does elevate the $\dot{V}O_2$ of athletic individuals whilst exercising at relatively high intensities. The results would also imply that the observed elevated $\dot{V}O_2$ (thermic effect) is associated with the subjects perceiving the exercise to be more difficult. However, further research is required to investigate whether such effects are present during steady-state exercise and to determine the precise implications for the performance of the 'athlete'.

Acknowledgements

The authors would like to thank Dr S. Bulleid for her technical assistance and Mr F. M. Holliday (University of Loughborough) for his advice on the statistical analysis of the results. They would also like to thank all the athletes for their willing participation in the investigation.

References

1 Vander AJ, Sherman JH, Luciano DS. *Human Physiology.* Maidenhead: McGraw-Hill, 1980.

2 Hoar WS. *General and Comparative Physiology.* London: Prentice Hall Inc., 1983.

3 Suttie JW. *Introduction to Biochemistry.* London: Holt, Rinehart and Winston, 1977.

4 Bray GA, Whipp BJ, Sankar NK. The acute effects of food intake on energy expenditure during cycle ergometry. *Am J Clin Nutr* 1974; **27**: 254–9.

5 Zahorska-Markiewicz B. Thermic effect of food and exercise in obesity. *Eur J Appl Physiol* 1980; **44**: 231–5.

6 Welle S. Metabolic responses to a meal during rest and low intensity exercise. *Am J Clin Nutr* 1984; **40**: 990–4.

7 Segal KR, Presta E, Gutin B. Thermic effect of food during graded exercise in normal weight and obese men. *Am J Clin Nutr* 1984; **40**: 995–1000.

8 Segal KR, Gutin B. Thermic effects of food in lean and obese women. *Metabolism* 1983; **32**: 581–9.

9 Bird SR, Hay S. Pre-exercise food and heart rate during submaximal exercise. *Br J Sports Med* 1987; **21**: 27–8.

10 Winget CM, deRoshia CW, Holley DC. Circadian rhythms and athletic performance. *Med Sci Sports Exerc* 1985; **17**: 498–516.

11 Hill DW, Cureton KJ, Collins MA, Gisham SC. Diurnal variations in responses to exercise of 'morning types' and 'evening types'. *J Sports Med Phys Fitness* 1988; **28**: 213–19.

12 MacDougall JD, Wenger HA, Green HJ, eds. *The Physiological Testing of the Elite Athlete.* Canadian Association of Sports Sciences, 1982.

13 Thoden JS, Wilson BA, MacDougall JD. Testing aerobic poweer. In: MacDougal JD, Wenger HA, Green JH, eds. *The Physiological Testing of the Elite Athlete.* Canadian Association of Sports Sciences, 1982.

14 McConnell TR. Practical considerations in the testing of $\dot{V}O_{2\,max}$ in runners. *Sports Med* 1988: **5**: 57–68.

15 Borg A. Perceived exertion: a note on history and methods. *Med Sci Sports* 1973; **5**: 90–3.

16 Cohen L, Holliday FM. *Statistics for Social Scientists.* London: Harper and Row, 1982.