5-2018

Energetics Among Collegiate Cross-Country Runners

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An honors thesis presented to the
Department of Anthropology,
University at Albany, State University Of New York
in partial fulfillment of the requirements
for graduation with Honors in Human Biology
and
graduation from The Honors College.

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May, 2018

Abstract

The purpose of this study is to determine the energy expenditure of collegiate long distance runners in practice sessions and determine how energetics differ between six male and six female runners. Previous research has looked at aerobic capacity, injury risk, and dietary adequacy. Currently, there is little research on energetics (calories expended during a given running period) throughout a season. Energy expenditure was measured during nine practice sessions by using heart rate monitors. From this data we calculated mean submaximal heart rate (SHR) and used the Flex-Heart Rate method to estimate total energy expenditure (TEE) of the runners. We compared mean SHR and energy expenditure between males and females and within each runner throughout the cross-country season to determine if there were any adaptive changes in endurance ability. The results of this study are advantageous to coaches and athletes, who can utilize the results to create more effective training strategies. Results show an overall decrease in mean SHR and TEE by the end of the season compared to the beginning. Although males appear to show greater energy expenditure in endurance activity compared to females, there is no difference in energy costs when body mass is taken into account. These findings suggest that through daily endurance exercise, individuals are able to adapt to a given level of activity by becoming more physiologically efficient.

Acknowledgements

Thank you to the UAlbany Cross-Country coaches and runners, without you this would not have been possible. A special thank you to Dr. Ocobock for all of her wisdom and patience throughout this process. I would also like to thank Samantha Shaiman and Hana Turner for all of their work as research assistants and to my family and friends for all of their support.

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Introduction

Cross-Country running is an endurance sport, which dates back to the 19th century (Heywood, 2016). In the United States, there are 307 universities at the Division 1 level that have men's cross-country teams and 333 Division 1 universities that have women's teams. Teams such as these average 50 runners (Cross Country, n.d.). Cross-country race courses differ between men and women. The men's distance is at least 4000 meters. Championship races range from a minimum of 8000 meters to a maximum of 10,000 meters. The women's distance must be at least 3,000 meters and women's championship races range from a minimum of 5000 meters to a maximum of 6000 meters. The course is typically restricted to grasslands, fields, and woods. Thus, golf courses, parks, and specifically designed courses are most suitable for such events and are recommended. The boundaries for the courses are marked with natural or artificial markers and are continuous throughout the entire course. Markers are also used to indicate miles/kilometers throughout the course (National Collegiate Athletic Association, 2017). Times for cross-country races differ due to variations in courses and conditions, thus it is difficult to determine an average race time.

All runners that finish the race are given an over-all finishing place, however, only the first seven runners on a team are used for scoring places, which is the sum of the runners place. The place finish of the first five runners determines the overall team score. The team with the lowest score is the winner (teams ranked lowest to highest). Despite sixth and seventh place finishers not scoring points, their placement is important in increasing team scores over other opponents. When looking at top place finishers, there are various features that these individuals share in terms of anthropometrics, biomechanics, and especially aerobic capacity.

Anthropometrics

Distance runners typically exhibit lower body mass and low subcutaneous fat. Numerous studies have investigated the anthropometrics of distance runners and found these elements to be consistently influential to race times (Anderson, 1996; Bale, Rowell, & Colley, 1985; Burke & Brush, 1978; Friedrich et al., 2014; Lucia et al., 2006; Williams, Cavanagh, & Ziff, 1987; Gordon et al., 2017). For instance, in a study performed by Loftin et al., low run times had moderate to high correlation with low body composition (2007). Skin fold thickness analyses suggest that better runners appear to have smaller skinfold values, thus indicating lower levels of body fat (Bale, Rowell, & Colley, 1985; Burke & Brush, 1978; Friedrich et al., 2014). Overall, male and female runners of larger size expend more kilocalories and run slower times compared to smaller runners (Loftin et al., 2007). Such characteristics play a role in differentiating elite from average runners. Elite endurance athletes consistently have better running economy, VO_2max, and anaerobic threshold, which distinguish them from average endurance athletes (Lorenz et al., 2013; Gordon et al., 2017).

Biomechanics

There is no single factor that solely contributes to running success, yet there are certain variables that seem to have more of an influence on running economy than others. Various studies have examined kinematic variables such as shank angle, trunk angle, vertical oscillation, maximum plantar flexion angle, minimum knee velocity, wrist excursion, and maximum knee flexion (Williams & Cavanagh, 1987). As demonstrated by Conley and Krabenbuhl when investigating elite runners in a 10km race, the variation seen in race performance time could be explained by running economy variations among the runners with similar abilities and VO_2max (1980). Experienced runners naturally choose the most economical stride length. Deviations from chosen stride length often lead to increased oxygen requirements, thus indicating optimal stride frequency is established by perceived exertion. The ability of runners to naturally choose their ideal stride frequency and length is known as self-optimization and has been shown to occur in both experienced and inexperienced runners (Barnes, Mcguigan, & Kilding, 2014; Moore, 2016; Anderson, 1996; Hunter, Ward, & Tracy, 2017).

Aerobic Capacity

Aerobic capacity becomes increasingly important as running distance increases. Among elite runners, maximal oxygen uptake (VO_2max) is relatively similar, but it is an important determining factor in athletic performance (Thompson, 2017). Using VO_2max provides a way to quantify one's ability to resynthesize aerobic ATP, thus reflecting an individual's maximum level of aerobic fitness (McArdle, Katch, & Katch, 2010; Abut & Akay, 2015; Parak et al., 2017; Ghosh; 2004). Various studies have found increased VO_2max is related to greater endurance capacity (Shaw et al., 2015; Vandbakk et al., 2017; Sandbakk et al., 2016a; Sandbakk et al., 2016b; Carlsson, Tonkonogi, & Carlsson, 2016; Gordon et al., 2017; Czuba et al., 2013). Research has also demonstrated the strong positive relationship between VO_2max, heart rate, and running velocity in elite runners. Due to this relationship, it is possible to use heart rate to indicate energy demands and as a way to observe any variations in running economy during training sessions (Reis, Van den Tillaar, & Marques, 2011; Habibi et al., 2014; Ghosh, 2004). Parak et al. have demonstrated the ability of using optical heart rate monitors to calculate accurate measurements in heart rate, VO_2max, and energy expenditure while running (2017).

Furthermore, both increased VO_2max and energy expenditure are related to enhanced endurance (Stöggl et al., 2016). Studies have found daily energy expenditure of highly trained female endurance runners to be 2,990 ± 415 kcal/d (Edwards et al., 1993) and 2,826 ± 312 kcal/d (Schulz et al., 1992). Similarly, average energy expenditure in male Kenyan endurance runners was found to be 3,491 kcal/d (Fudge et al., 2006) and 3,784 ± kcal/d in male Japanese middle and long distance runners (Motonaga et al., 2006).

Summary

Previous research has looked at aerobic capacity, injury risk, and dietary adequacy. This research included collegiate level male and female cross-country runners from a public university during daily practice sessions. The purpose of this study is to measure energy expenditure throughout practice sessions in a cross-country season. This was accomplished by placing heart rate monitors on each runner. Mean submaximal heart rate and energy expenditure during practice sessions will allow coaches and athletes to obtain greater knowledge of the effectiveness of training sessions, which can aid in developing more effective practice sessions and ultimately better running times in competition.

Subjects and Methods

The subjects (N=12) were collegiate level cross-country runners competing for the University at Albany, State University of New York (SUNY) in the Division 1 America East Conference. Subjects included 5 males (ages 19-21; height 177.38 ± 5.66; weight 66.24 ± 3.65) and 5 females (ages 18-21; height 165.98 ± 7.45; weight 53.60 ± 4.53) (Table 1). Heart rate and environmental data (Table 2) were collected during nine practices throughout the Fall cross-country season.

Table 1. Subject biometrics

Subject	Sex	Height (cm)	Weight (kg)	Age
XCF-1	F	162.6	49.0	18
XCF-2	F	170.2	53.5	20
XCF-3	F	167.6	54.9	19
XCF-4	F	177.8	61.7	19
XCF-5	F	160.2	52.6	21
XCF-6	F	157.5	49.9	20
XCM-1	M	177.8	68.0	21
XCM-2	M	188.0	69.0	21
XCM-3	M	172.7	61.2	19
XCM-4	M	172.7	62.1	21
XCM-5	M	175.3	69.9	20
XCM-6	M	177.8	67.1	19

Table 2. Peak temperature, humidity, and weather conditions of recorded practices

Date	Peak Temperature During Practice Time (F)	Conditions	Humidity (%)
9/26/17	88	Sunny, Humid	69
10/2/17	68	Sunny, Neutral	39
10/4/17	77	Sunny	50
10/6/17	62	Cloudy, Wet Ground	75
10/10/17	77	Sunny, Slight Wind	51
10/20/17	71	Sunny	31
10/31/17	51	Mostly Cloudy	45
11/2/17	53	Rain	86

ActiTrainer units are combined 3-axis accelerometers and heart rate monitors. All subjects wore the units during the entirety of nine practice sessions, including warm-up and cool-downs. The ActiTrainer unit is able to collect heart rate data every ten seconds for the duration of the practice. This data was used to convert each runner’s metabolic rate by employing the flex heart rate method. Subjects were also measured for their height and weights, which were input into sex specific published equations from Dugas et al. (2005) in order to calculate energy expenditure.

Dugas et al., 2005 HR equations:

Men EE (kj/min) = -16.1 + (HR*0.194) + (0.311*previous min HR) + (-0.002 *HR*previous minHR)+(-0.597*weight_kg)+ (0.353*age_yr)+(0.007*HR*weight_kg)

Women EE (kj/min) = -20.2+ (HR*0.397) + (0.155*previous min HR) + (-0.001 *HR*previous minHR)+(-0.174*weight_kg)+ (-0.08*age_yr)+(0.001*HR*weight_kg)

Estimates were converted from kilojoules per minute to kilocalories per minute. Total energy expenditure (TEE) data is presented in an uncorrected and a corrected form. At high levels of energy expenditure, the Flex Heart Rate method is known to overestimate TEE by ~17% (Ocobock, 2016). The corrected values of TEE take this overestimation into account. After calculating energy expenditure from the collected data, runners were analyzed separately for their individual practice session. Minimum, maximum, and average heart rates were established per athlete and total energy expenditure (kcal) of individual runners was also calculated for the entire practice session.

Results

Mean HR across all practices was 128 ± 3.9 bpm for females and 125 ± 5.9 bpm for males. Mean uncorrected TEE for females was 1059 ± 166.9 kcal and 1348 ± 247.4 kcal for males. When corrected these values were 879 ± 138.5 kcal and 1119 ± 205.3 kcal, respectively (Table 3). Average TEE per kilogram of body mass was 20 ± 3.4 kcal/kg for females and 21 ± 2.1 kcal/kg for males. When corrected for, these values were 16 ± 2.8 kcal/kg and 17 ± 1.8 kcal/kg, respectively (Table 4). There was no significant difference between men and women for mean HR (p=0.22). However, a significant difference was found between males and females for TEE (uncorrected and corrected) (p=0.002). When body mass was taken into account, there was no significant difference in TEE between males and females (uncorrected and corrected) (p=0.77). Additionally, it was found that the average HR for individuals from the first practice (132 ± 6.4 bpm) to the final practice (120 ± 15.2 bpm) was statistically significant (p=0.05). This was also true for corrected TEE per body mass (21 ± 2.5 kcal/kg to 11 ± 9.2 kcal/kg) (p=0.006).

Table 3. Male and female averages for heart rate and total energy expenditure (corrected and uncorrected)

Practice	Female Average HR (bpm)	Male Average HR (bpm)	Female Average TEE (kcal)	Male Average TEE (kcal)	Female Average TEE Corrected (kcal)	Male Average TEE Corrected (kcal)
9/26/17	130 ± 6.1	133 ± 6.7	1382 ± 99.2	1730 ± 248.3	1147 ± 82.3	1436 ± 206.1
10/2/17	129 ± 8.6	129 ± 5.8	1080 ± 90.3	1424 ± 164.7	896 ± 75.0	1182 ± 136.7
10/4/17	129 ± 5.6	123 ± 8.1	1145 ± 54.7	1542 ± 183.9	950 ± 45.4	1280 ± 152.7
10/6/17	129 ± 7.8	117 ± 4.9	990 ± 167.3	1204 ± 173.1	821 ± 138.9	999 ± 143.7
10/10/17	134 ± 7.1	129 ± 13.0	1050 ± 116.5	1250 ± 351.1	871 ± 96.7	1037 ± 291.4
10/20/17	126 ± 11.1	123 ± 17.2	1035 ± 208.7	1541 ± 322.7	859 ± 173.2	1279 ± 267.8
10/31/17	124 ± 8.5	122 ± 8.4	1135 ± 115.6	1294 ± 368.1	942 ± 95.9	1074 ± 305.5
11/2/17	122 ± 6.4	131 ± 0.3	761 ± 2.2	1271 ± 1.2	632 ± 88.3	1055 ± 81.0
11/6/17	126 ± 12.3	117 ± 19.9	954 ± 792.9	875 ± 358.1	792 ± 658.1	726 ± 297.2

Table 4. Averages in total energy expenditure (corrected and uncorrected) for individuals

Subject	Average TEE (kcal)	Average TEE Corrected (kcal)	Average TEE/Body Mass (kcal/kg)	Average TEE/Body Mass Corrected (kcal/kg)
XCF-1	1027 ±185.1	853 ±153.6	21 ± 3.8	17 ± 3.1
XCF-2	1345 ±346.0	1117 ± 287.2	25 ± 6.5	21 ± 5.4
XCF-3	1001 ± 301.3	831 ± 250.1	18 ± 5.5	15 ± 4.6
XCF-4	957 ± 305.1	794 ± 188.0	16 ± 3.7	13 ± 3.0
XCF-5	1125 ± 133.7	934 ± 111.0	21 ± 2.5	18 ± 2.1
XCF-6	897 ± 365.8	745 ± 303.6	18 ± 7.3	15 ± 6.1
XCM-1	1275 ± 277.0	1058 ± 229.9	19 ± 4.1	16 ± 3.4
XCM-2	1544 ± 242.9	1282 ± 202.9	22 ± 3.5	19 ± 2.9
XCM-3	1355 ± 270.1	1124 ± 224.2	22 ± 4.6	18 ± 3.7
XCM-4	1421 ± 394.5	1179 ± 327.5	23 ± 6.3	19 ± 5.3
XCM-5	1287 ± 508.2	1069 ± 421.8	18 ± 7.3	15 ± 6.0
XCM-6*	729	605	11	9

Discussion

This study analyzed mean SHR and energy expenditure of runners throughout a cross-country season over the course of nine practices. These variables were compared between males and females and within each runner. Subjects displayed decreased mean SHR and energy expenditure from the first practice to the last. These findings suggest adaptations to daily endurance exercise occurred throughout the season and were responsible for the reduction in SHR and aided the body in becoming more efficient in terms of running capacity. As a result, the body was able to expend fewer calories at a similar level of exercise intensity. Without taking body mass into account, men expend more calories in endurance exercise than women. However, when looking at energy expenditure per kilogram of body mass, these differences are negligible suggesting there is no metabolic cost difference between males and females in this study.

VO_2max, skeletal muscle adaptations, and neuromuscular adaptations, such as mitochondrial biogenesis and autophagy could also play a role in improving running economy by increasing oxygen transport and utilization (Chen, Erlich, & Hood, 2018; Mueller et al., 2017; Southern et al., 2017; Skovgaard et al., 2018; Fransson et al. 2018). Many have found increased VO_2max and other adaptive responses; such as reduced submaximal heart rate can occur over the course of 6-12 weeks due to endurance training (Carlsson et al., 2017; Tjønna et al., 2013; Carter, Banister, & Blaber, 2003; McArdle et al., 1978; Anderson & Henriksson, 1977). For example, a nine-week study on endurance training found a total increase of 23% in VO_2max in addition to decreased SHR (Hickson et al., 1981).

Various studies have illustrated fluctuations in TEE during the training season for endurance athletes, as evidenced by the review performed by Heydenreich et al. (2017). However, most studies focus on energy intake, body composition, or energy costs of activity for a short period, rather than directly comparing individual's adaptations in energy expenditure from the beginning of a competitive season to its end (Woods et al., 2018; Paulin et al., 2015; Hall, 2010; Drenowatz et al., 2012; Bourrilhon et al., 2009; Sjödin et al., 1994).

It should be noted that weather conditions also impact heart rate. Evidence suggests in conditions, such as heat that increases in heart rate may be related to an increase in the percentage of peak oxygen uptake (Arngrímsson et al., 2003). Therefore, it is important to consider the conditions in which these subjects were running (ie: temperature, humidity, or precipitation), since they may have impacted the collected measures on a given day. As such, in a future analysis, the environmental conditions will be examined to determine if they had an impact on the participants in this study.

Limitations

There are various limitations to this study. Firstly, biomechanics and additional physiological measures were not looked at in this investigation. Therefore, it is possible that a number of other factors could have also contributed to improvements in running capacity. Additionally, subject number was small and self-selected, since university runners have been running for years prior to the start of their collegiate freshman year. It should also be noted that one subject was only able to participate in one practice; consequentially there was no data to compare throughout the season. Due to these limitations, care should be taken when generalizing results to the public

Conclusion

Through daily endurance training subjects demonstrated physiological adaptations to improve their running efficiency over the course of a cross-country season. Comparatively, subjects displayed reduced SHR and total energy expenditure by the end of the season compared to the first practice. Although men appear to have a greater energy cost in endurance activity than women, that difference is entirely mediated by body mass. These results suggest the human body is able to adapt to given levels of training intensity over time in order to become more economical. This work also reveals the need to further investigate other factors contributing to endurance adaptations.

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