Pre-Race Dietary Carbohydrate Intake can Independently Influence Sub-Elite Marathon Running Performance

Authors G. Atkinson[1], C. E. Taylor[1], N. Morgan[2], L. R. Ormond[2], G. A. Wallis[2]

Affiliations [1] Liverpool John Moores University, RISES, Liverpool, United Kingdom
[2] GlaxoSmithKline Nutritional Healthcare, Brentford, United Kingdom

Key words
- nutrition
- endurance
- multiple regression
- race preparation
- marathon

Abstract

We examined whether selected anthropometric and nutritional factors influenced field-based marathon running performance. An internet-based data collection tool allowed competitors in the 2009 London Marathon (n = 257, mean ± SD age: 39 ± 8 years, finish time: 273.8 ± 59.5 min) to record a range of anthropometric, training and nutritional predictors. Multivariate statistical methods were used to quantify the change in running speed mediated by a unit change in each predictor via the 95% confidence interval for each covariate-controlled regression slope (B). Gender (B = 1.22 to 1.95 km/h), body mass index (B = −0.14 to −0.27 km/h), training distance (B = 0.01 to 0.04 km/h) and the amount of carbohydrate consumed the day before the race (B = 0.08 to 0.26 km/h) were significant predictors, collectively accounting for 56% of the inter-individual variability in running speed ($P < 0.0005$). Further covariate-adjusted analysis revealed that those competitors who consumed carbohydrate the day before the race at a quantity of > 7 g/kg body mass had significantly faster overall race speeds ($P = 0.01$) and maintained their running speed during the race to a greater extent than with those who consumed < 7 g/kg body mass ($P = 0.02$). We conclude that, in addition to gender, body size and training, pre-race day carbohydrate intake can significantly and independently influence marathon running performance.

Introduction

The marathon foot-race (26 mile 385 yards, 42.195 km) is considered by many as the ultimate test of endurance performance. Once the preserve of the elite athlete, tens of thousands of sub-elite runners now undertake the challenge of the marathon in mass-participation running events held all over the world [6]. In parallel with this popularity, considerable effort has been directed at understanding the scientific and medical aspects of marathon running in order to optimize the performances, health and safety of the vast demographic of individuals participating in marathon running events [28, 32].

With respect to marathon performance, both physiological (e. g., maximal oxygen uptake, lactate threshold and running economy, [27]) and nutritional factors (e. g., glycogen availability, [7]) are known to influence long-distance running performance. The understanding of the role these factors play in affecting endurance performance has been largely derived from laboratory-based experiments which is an approach that maximizes internal validity for accurate estimation of the influence of a specific factor or intervention. However, external validity can be limited in laboratory-based experiments which could lead to ambiguity over whether the specific factor or intervention is effective or relevant in real-world conditions [3]. As such, there have been calls for complementary research approaches to laboratory-derived data in order to further understand the specific factors affecting actual running performance in the field environment [4].

One complementary approach is to analyse real marathon race performances in the field and explore correlations with additional information gathered on specific factors that could affect performance. This approach has been applied to the study of mass participation endurance running race performances and in the context of physical characteristics it is clear that gender [26], anthropometry [20], exercise training [16] and to a lesser extent age [26] can affect endurance running race performance. However, the relative importance of these factors for marathon performance has not been studied. In addition,

accepted after revision
February 12, 2011

Bibliography
DOI http://dx.doi.org/10.1055/s-0031-1273739
Published online: May 17, 2011
Int J Sports Med 2011; 32: 611–617 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

Correspondence
Prof. Greg Atkinson
Liverpool John Moores University
RISES
Henry Cotton Campus
L3 2ET Liverpool
United Kingdom
Tel.: + 44/0151/904 62 31
Fax: + 44/0151/904 62 84
G.atkinson@ljmu.ac.uk

Table 1 Anthropometric, training, performance and dietary characteristics of the research participants.

Variable	Mean (±SD)	Range
Age (years)	39±8	21–70
Body mass (kg)	71±13	44–117
Height (cm)	173±9	147–195
Body mass index (kg/m^2)	23.6±2.9	17.0–36.1
Longest training run (km)	32.7±5.6	0.0–64.4
Number of previous marathons	3±7	0–59
Training distance during the 5th week before the race (km/week)	54±22	0–139
In-race Perceived Exertion		
5km	11±2	6–17
40km	17±2	6–20
In-race Feeling Scale		
5km	4±3	−4 to +5
40km	−1±3	−5 to +5
In-race Felt Arousal Scale		
5km	4±1	1–6
40km	4±1	1–6
Carbohydrate intake		
Pre-race day (g/kg)	5.0±1.9	0.4–14.7
Race day breakfast (g/kg)	1.7±0.8	0.8–5.9
Within race (g/h)	23±15	0.0–62.4
Energy intake		
Pre-race day (kcal/d)	2458±873	
Race day breakfast (kcal)	638±314	
Within race (kcal)	415±219	
Fluid intake		
Pre-race day (L/d)	3.37±2.94	0.55–9.70
Race day breakfast (L)	1.12±0.52	1.00–3.74
Within race (L/h)	0.39±0.29	0.00–1.83
Finish time (hh:min:ss)	04:30:28±00:52:35	2:43:41–7:20:20
Speed (km/h)	9.71±1.85	5.75–15.47

although the eating behaviours of marathon runners have been analysed leading up to a race [21] and it has been known since the 1920s that nutrition can be important for marathon performance [25], studies to date have not clearly defined the relative importance and influence of nutrition on actual field-based marathon performance [7].

Therefore, the aim of this study was to establish the extent to which selected anthropometric and nutritional factors influence field-based marathon running performance. In order to achieve this, the actual performances along with a range of information related to specific factors that may affect marathon performance was collected from a large number of participants competing in a mass participation marathon race. This information was subject to multivariate statistical methods which enabled the identification and calculation of the extent to which the recorded factors can independently influence real-world, field-based marathon running performance. Our primary research question was whether nutritional factors influenced marathon running performance independently from other anthropometric and training factors.

Methods

Research participants

In accordance with the Declaration of Helsinki and the ethical guidelines for the journal [19] runners registered to participate in the 2009 Flora London marathon were invited to participate in this study through advertisements placed in national running media. Informed consent to participate was provided through registration via an internet-based online data collection tool. The first 400 respondents were invited to participate in the study with a total of 257 runners electing to continue to participate following the initial registration. The mean (±standard deviation, SD) age and recorded marathon finish time of these participants was 39 (8) yrs and 273.8 (59.5) min, respectively. Further characteristics of the study sample population are presented in **Table 1**.

Research design

The main research design was correlational in nature with the identification of specific factors influencing mean race running speed for the whole marathon set as the primary study outcome. A secondary analysis involved examining within-race changes in running speed with particular reference to the degree to which running speeds deteriorated as the race progressed. Performance data for the research participants was provided to the investigative team by the London Marathon organisers shortly following the race. This information is available in the public domain. In order to explore the specific factors that may affect race performance the research participants returned to the internet-based online data collection tool at specific periods in the lead up to and after the marathon to enter selected information relating to their physical and nutritional characteristics.

Data collection and synthesis

Using the internet-based data collection tool, participants were required to report their age on race day (26.4.2009), gender, weight, height, and details related to their training history along with completing detailed training and food diaries during the weeks and days leading up to the marathon race day and for the day of competition itself. Self-reported weekly training diaries were collected for the 5 weeks leading up to the marathon. Participants recorded the number of marathons completed previ-

ously and the amount of training (in km) completed during each week for the 5 weeks prior to the race. Food diaries were collected for all food and drink consumed over the 24 h period for the day before race day ('pre-race day nutrition'), dietary intake on the morning of the race ('race-day breakfast') and during the race itself ('in-race nutrition'). Participants were provided with clear instructions for recording dietary intake which included the reporting of estimations of time of consumption, portion size and other useful descriptive information (such as cooking method or brand name). The dietary information reported by the research participants was subsequently analysed by a blinded and independent nutritionist who was experienced in the use of WinDiets 2005 (Schoolhill, Aberdeen, UK) for food diary analysis. The dietary analysis was summarised as the total carbohydrate, total energy and total fluid intake for each specific recording period (i.e., pre-race day, race-day breakfast, in-race).
Participants also provided responses to psychological scales to assess ratings of perceived exertion (15-point scale [5]), pleasure-displeasure (11-point Feeling Scale, [17]) and perceived activation/arousal (6-point Felt Arousal Scale, [35]) at specific points during the race (at 5 km and 40 km, identified by famous landmarks in the race). Finally, the race time and 5 km split-times for each runner in the study was collected using the information provided by the transponders issued to all race participants in advance of the race (ChampionChip). The timing data was made available in the public domain on the London Marathon website following the race but also forwarded directly to the principal investigators.

Statistical analysis

The statistical analysis of the complete data set was performed by a biostatistician who was not involved in data collection. The data were analysed using a combination of hierarchical and step-wise multiple regression models with mean running speed as the primary outcome variable [3]. In the first stage of the analysis, stepwise multiple regression models were used to identify the most important predictors within each of the following collections of specific factors; inter-individual characteristics (age, gender, body mass index [BMI]), training characteristics (longest training run, weekly training distances), in-race subjective feelings (perceived exertion, pleasure-displeasure, perceived activation/arousal) and dietary information (pre-race nutrition, race-day breakfast, in-race nutrition). Significant predictors from each of these analyses were then entered into an overall stepwise multiple regression model. Predictor entry into the model was the backwards type [3,13]. The alpha level of significance for inclusion of a predictor in this exploratory model was 0.1. The primary statistical outputs from this approach were the 95 % confidence intervals for the beta co-efficient of each covariate-controlled regression slope (B). This represents the change in running speed mediated by a unit change in a specific factor.
On the basis of dietary guidelines for athletes (7–10 g carbohydrate per kg body mass for optimal muscle glycogen storage to carbohydrate load for an endurance event, [8]), the sample was also divided into those athletes who ingested more than 7 g/kg carbohydrate during the day preceding the race (n = 30) and those who did not (n = 216). Using the 5 km split-times, the within-race profile of running speed was compared between these 2 sample groups using a 2-factor (group × race-split) repeated measures analysis of covariance model. This statistical model was covariate controlled for the influence of the other factors found to influence running speed (gender, BMI and pre-race training distance). The sample size for this analysis does not total to 257 due to data missing at random.
In a sensitivity analysis, we also pair-matched 30 runners who consumed < 7 g/kg of carbohydrate during the day preceding the race with the 30 runners who ingested more than this cut-off value. 15 men and 15 women were pair-matched in terms of BMI. First, participants were excluded if their BMI was outside the range of the > 7 g/kg runners. Then participants were removed at random throughout the range of BMI until 15 men and 15 women remained for analysis. Differences between these 2 samples were analysed with independent t-tests and ANCOVA. Within-race profiles of running speeds were also compared between these samples using the same group x race-split repeated measures analysis as above.

Results

▼

Table 1 summarises the data for the specific factors for which information was gathered in this study and utilised in the statistical analysis to identify significant predictors of performance (i.e., data relating to anthropometric, physical, training and performance characteristics and dietary intake, respectively).
Table 2 presents the specific factors that were identified as being statistically significant predictors of race speed in the overall step-wise regression model. The primary statistical output from this approach was the 95 % confidence intervals for each covariate-controlled regression slope (*B*). This represents the change in running speed mediated by a unit change in a specific factor (e.g., gender was identified to influence running speed by 1.59 km/h [*B* = 1.22 to 1.95 km/h]). In addition to gender, other specific factors that independently influenced running

Table 2 Statistical details of the specific factors that significantly (P < 0.10) predicted marathon running speed in the overall statistical model.

Specific factor	Beta (95 % CI)[a] (km/h)	Standardised Beta[b]	Colinearity tolerance[c]	Colinearity VIF[d]
Gender (male/female)	1.59 (1.22–1.95)	0.42	0.84	1.19
Body mass index	− 0.20 (− 0.27– − 0.14)	− 0.31	0.77	1.30
Longest training run	0.038 (− 0.003–0.081)	0.09	0.89	1.13
Training distance during 5th week before the race	0.018 (0.009–0.027)	0.21	0.65	1.54
Training distance 2nd week before the race	0.024 (0.013–0.035)	0.24	0.64	1.56
Carbohydrate intake during day prior to race	0.17 (0.078–0.26)	0.17	0.91	1.10

[a] The beta coefficient (with 95 % confidence intervals, CI) represents the change in running speed (km/h) mediated by a unit change in a specific factor. For example, gender influenced running speed by 1.22–1.95 km/h
[b] The standardised beta coefficient shows the expected change in running speed for every 1 standard deviation change in the specific factor
[c] An acceptable criteria for non-serious multicolinearity between predictors is that all variance inflation factors (VIF) are < 10 [13]
[d] An acceptable criteria for non-serious multicolinearity between predictors is that all colinearity tolerance statistics are > 0.2 [13]

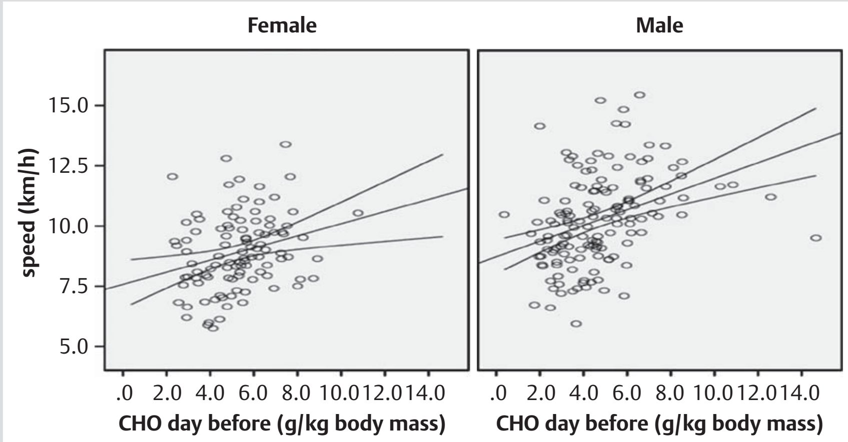

Fig. 1 Scatterplots for the relationship between carbohydrate intake during the day preceding race-day and marathon running speed in male and female athletes. Least squares linear regression slopes are fitted together with the associated 95 % prediction intervals.

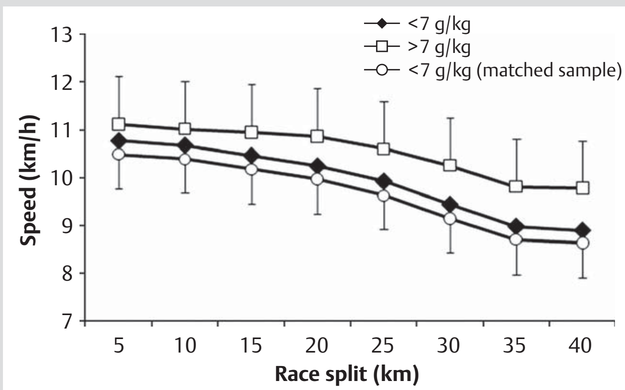

Fig. 2 Within-race split speeds for the runners who consumed >7 g/kg and <7 g/kg of carbohydrate during the day before the race. Also shown is the split speeds for the matched sample of 30 runners who consumed <7 g/kg of carbohydrate.

speed included BMI (B = −0.27 to −0.14 km/h), training distance during the 2nd week before the race (*B* = 0.013 to 0.035 km/h) and the amount of carbohydrate (g/kg) ingested during the day before the race (*B* = 0.078 to 0.26 km/h). The specific influence of pre-race day carbohydrate ingestion (g/kg) on race performance is highlighted in ▸ **Fig. 1**, which shows the scatter plots and associated least squares regression lines for runners of both sexes. The overall regression model explained 56 % of the variability in race speed, and this coefficient of determination reduced only slightly when gender was removed from the model as a highly influential variable. The multicolinearity statistics which describe the degree of correlation between separate predictors are low according to established criteria [13] (▸ **Table 2**).

The other specific factors for which information was gathered and entered into the statistical analysis (e. g., age, subjective feelings, other dietary information) were not identified as being significant predictors (P > 0.1) of race speed when considered in the overall statistical model.

In a secondary analysis that was covariate-controlled for all other independent predictors of performance, those runners who reported to ingesting > 7 g carbohydrate per kg body mass the day before the race were found to have a significantly greater overall race speed than those who did not (main effect of group: P = 0.01). These runners were also found to have a shallower decline in within-race running speed compared with runners consuming < 7 g carbohydrate per kg body mass (group by split interaction: P = 0.02) such that the largest difference in running speed between the 2 different carbohydrate intake groups occurred at the end of the marathon (▸ **Fig. 2**).

When 30 runners who consumed less than 7 g/kg of carbohydrate on pre-race day were pair-matched to the 30 runners who consumed more than this amount, mean overall race speed also differed significantly between these 2 cohorts (9.31 vs. 10.56 km/h, P = 0.004). Apart from consumed carbohydrate, these 2 samples did not differ significantly in terms of any other variable, including age, BMI, training data and the number of previous marathons completed (▸ **Table 3**). An ANCOVA model was also used to examine differences between groups in running speed with longest training run and training distance at 2 and 5 weeks as covariates. The difference between groups in running speed remained statistically significant (95 %CI: −1.6 to −0.10 km/h, P = 0.03). The interaction between group and race split remained statistically significant for this pair-matched analysis (P = 0.05) and the trend was the same; the reduction in running speed was less marked for the runners who consumed > 7 g/kg of carbohydrate so that the greatest difference in running speeds between cohorts was observed between 35–40 km (▸ **Fig. 2**).

Discussion

The aim of this study was to use a multivariate statistical approach to establish the extent to which selected anthropometric and nutritional factors influence marathon running performance. The main new finding from using this experimental approach is the demonstration that pre-race day carbohydrate intake is significantly related to real-world, field-based marathon running performance. The present study also confirms previous reports that gender, body size and training are further specific factors that can influence inter-individual differences in marathon running speed.

In the present study a number of specific physiologic and nutritional factors were collected and entered into an exploratory statistical model to identify specific predictors of marathon running performance within this cohort of research participants. Notably, the amount of carbohydrate ingested the day before race-day remained as a significant predictor of marathon race speed in the eventual statistical model (i. e., pre-race day carbohydrate intake significantly predicts marathon running speed).

Table 3 Mean (SD) values for the 30 runners consuming >7 g/kg of carbohydrate the day before race-day and the 30 pair-matched runners who consumed <7 g/kg of carbohydrate. Only differences in running speed and carbohydrate intake reached statistical significance (P<0.05). An ANCOVA model was also used to examine differences between groups in running speed with longest training run and training distance at 2 and 5 weeks as covariates. The difference between groups in running speed remained statistically significant (95%CI: −1.6 to −0.10 km/h, P=0.03).

Variable	Low carbohydrate	High carbohydrate	95% CI (P-value)
Age (y)	39.5 (8.4)	38.0 (8.4)	−2.8 to 5.8 (P=0.50)
BMI (kg/m^2)	23.3 (3.3)	22.1 (2.2)	−0.3 to 2.6 (P=0.11)
No. of previous marathons	3.9 (11.0)	1.9 (3.3)	−2.3 to 6.2 (P=0.35)
Longest training run (km)	33.6 (7.0)	32.4 (7.2)	−2.5 to 5.0 (P=0.52)
Training distance (race day – 5 weeks) – km	49.7 (19.3)	56.8 (20.2)	−18.4 to 4.3 (P=0.22)
Training distance (race day – 4 weeks) – km	50.8 (17.5)	55.5 (26.1)	−16.5 to 7.1 (P=0.43)
Training distance (race day – 3 weeks) – km	44.4 (21.9)	52.1 (24.6)	−20.2 to 4.6 (P=0.21)
Training distance (race day – 2 weeks) – km	31.1 (14.5)	38.4 (18.8)	−16.1 to 1.8 (P=0.12)
Training distance (race day – 1 week) – km	19.8 (18.0)	24.5 (18.2)	−14.3 to 5.0 (P=0.34)
Carbohydrate intake during pre-race day (g/kg)	4.7 (1.2)	8.5 (1.7)	−4.5 to −3.0 (P<0.0005)
Marathon speed (km/h)	9.31 (1.50)	10.56 (1.70)	−2.1 to −0.4 (P=0.004)

Furthermore, the results from the statistical model (▶ **Table 2**) indicated that for every 1 g/kg body mass increase in (pre-race day) carbohydrate intake, running speed would be predicted to increase by 0.17 km/h (95% CI, 0.08–0.26 km/h). Several authors have emphasised the importance of consuming a diet relatively high in carbohydrate in the days preceding a marathon (e.g., [7,30,31]) based on experimental observations of the role of carbohydrate availability and the capacity to perform prolonged endurance exercise [1,22]. Nonetheless, to the authors' knowledge this is the first experimental confirmation of the relative importance of preparatory carbohydrate nutrition for actual field-based marathon running performance.

A secondary analysis was also conducted to further explore the role of pre-race day carbohydrate intake on marathon performance. This analysis demonstrated that the mean running speed of those runners who consumed greater than 7 g carbohydrate per kg body mass the day before the race was 0.63 km/h (6.3%) faster than those who ingested less than this amount. In addition, those participants who consumed greater than 7 g carbohydrate per kg body mass the day before the race were also able to maintain running pace relatively better towards the end of the marathon (▶ **Fig. 2**). This is consistent with the findings of Karlsson and Saltin [22] who reported that the performance benefits of consuming a high carbohydrate diet prior to a 30 km running event were manifest through maintenance of race pace during the last 5 km of the race. It is also consistent with a recent report that used a computational approach to highlight the importance of body carbohydrate stores for the avoidance or delay in 'hitting the wall' during marathon running [31]. To the authors' knowledge, this is the first experimental confirmation that the quantity of carbohydrate consumed pre-race day can contribute to faster and better maintained marathon race speeds. Importantly, these benefits were demonstrated through a covariate-controlled analysis which means the findings are unlikely to be explained by differences in other factors (e.g., BMI, training) between the higher/lower carbohydrate intake groups.

The data in the present study showing the benefits of pre-race day carbohydrate intake for real-world marathon race performance is based on the collection of dietary information from 1 day prior to competition. Whilst it is known that a 1-day high carbohydrate dietary intervention is sufficient to significantly raise muscle glycogen stores [9] we cannot exclude the possibility that dietary habits over several days prior to the race day may have contributed to our observations [34]. In this respect, 68% of the participants in the present study reported that they had adopted a 'high carbohydrate diet' in the lead up to the marathon. This may indicate that the participants had altered their diet in the lead up to the race although it is interesting to note that for the pre-race day only 12% of participants reported to consume above 7 g carbohydrate per kg body mass, which we have used in this manuscript to identify the minimum amount of dietary carbohydrate necessary for optimal fuelling, [8]. This discrepancy suggests there are considerable differences in what participants perceive to be a high carbohydrate intake and in the dietary habits they adopted in practice. Nonetheless, collectively the data showing clear benefits of pre-race day carbohydrate intake on marathon performance strongly reinforces the importance of adhering to a high carbohydrate diet in preparation for endurance events as recommended by authoritative sources [18,33].

One unexpected result was the apparent lack of influence of dietary habits on running speed during the race day itself both immediately before and during the marathon. The amount of carbohydrate ingested during the race-day breakfast period was identified as a significant primary predictor of race speed in the first stage of the analysis although this factor did not remain as a significant performance predictor when included in the overall statistical model. We cannot rule out the possibility that a larger sample size would have allowed this particular predictor to remain statistically significant and future studies might seek to explore this further. Nonetheless, the apparent lack of influence of race day nutritional intake on running speed should not be interpreted to mean that they are not important factors. Rather, within the context of the present study it appears that other specific factors (including pre-race day carbohydrate intake, gender, training and BMI) are relatively more important than race-day nutritional intake. Indeed, consuming adequate food and fluid on the day of a marathon itself is a clearly established method to optimise the performances, health and safety of marathon runners and adhering to good practices in this respect should not be discouraged [10,29].

Consistent with previous reports examining factors that influence prolonged endurance running performance, the present study identified gender, BMI, and training as significant independent predictors of marathon running speed [15,20,26]. Gender exhibited a strong influence on race speed (▶ **Table 2**), with the time to complete the marathon ~15% longer for the women compared with the men in this cohort. The reasons behind the gender difference in performance is beyond the scope of this study but it is interesting to note that the magnitude of the gender difference observed in the present study is somewhat larger than the difference observed between world class male and female marathon competitors. For example, the gender difference in marathon finish times was ~15% in the present study vs. ~9% for the current world marathon record (2:15:25, Paula Radcliffe [GBR] – London, 13/04/2003; 2:03:59, Haile Gebrselassie [ETH] – Berlin, 28/09/2008) and the fractional difference in running speed was 1.15 in the present study which is larger than the gender fractional difference of approximately 1.12 reported for world class marathon runners [11]. This disparity is probably the result of the fact that our sample comprised mainly recreational runners and club athletes rather than world class athletes.

BMI was found to be a highly influential moderator of race running speed and in this case an increase in BMI was negatively associated with running performance. This is consistent with the general notion that BMI and body shape are important characteristics of successful endurance runners [2,24]. Nonetheless, experimental demonstration of the importance of anthropometric measures for successful performance as shown in the present study is not always reported and is more commonly observed when studying heterogeneous populations (e.g., in the present study BMI ranged from 17–33 kg/m^2) [2,23]. 3 selected aspects of training were the final factors found to predict marathon running speed in the present study. These included the longest single training run completed and the total training distance completed during both the 5th and 2nd weeks prior to the race day. However, it should be noted that the predictive utility of the longest pre-race training run only approached statistical significance and was also associated with a relatively small standardised beta coefficient (**Table 2**). While the data gathered in the present study was not exhaustive with respect to training characteristics, collectively it is interpreted to mean that cumulative training distance during the weeks preceding the marathon is a more relevant predictor of race speed than the 'one-off' longest training run completed.

Finally, in the present analysis we did not observe a significant influence of age or within race subjective psychological feelings on marathon performance. Performance losses have been considered an inevitable consequence of the aging process [35]. Nonetheless, Leyk et al. [8,36] have reported findings broadly consistent with the present study in that age-related marathon performance losses in a large cohort of participants were not evident until after 50–55 years of age. Thus, our data indicating that specific factors such as BMI, training and diet are more important determinants of marathon running performance than age supports the suggestion by other researchers [8,14,36] that regular physical training and lifestyle factors can help to offset age-related performance losses. In the present study, within-race subjective psychological feelings were also found to have little influence on overall running speed. Previously, Utter et al. [36] reported that supplementation of carbohydrate enabled marathon runners to exercise at higher intensities but did not affect their ratings of perceived exertion as compared to a placebo group. Collectively, this indicates that self-selection of running pace that occurs during the marathon is relative to the individual's perception and that this is relatively consistent between individuals irrespective of the influence of other factors on running speed.

Limitations

In our study, we did not collect data on personal best marathon times. Therefore, one issue is whether the runners who consumed more than 7 g/kg of carbohydrate during the day preceding race-day happened to also be superior in terms of personal best time and therefore more likely to record faster times during the race itself. However, if this performance-related factor was influential, one would expect other performance-related factors like number of previous marathons completed, training data and body mass index to differ between the samples in our pair-matched analysis. But this was not the case.

Participants self-reported all data pertaining to training and physical characteristics. Therefore, there may have been inaccuracy in these measurements. In a systematic review, Gorber et al. [15] found that self-reported height and body mass are slightly overestimated and underestimated, respectively. This would lead to an underestimation in BMI. Nevertheless, self-reported height and body mass data are satisfactorily accurate to be used in relatively large cross-sectional studies like ours [12] and it is difficult to conceive how any such random errors could have influenced our results, e.g., it would seem unlikely that the self-report data were more accurate for the participants consuming >7 g/kg of carbohydrate during the pre-race day compared with those participants consuming <7 g/kg of carbohydrate.

Conclusion

The present study confirms that gender, BMI and training clearly influence marathon running performance. In addition, although individual differences in race day diet did not strongly influence the marathon performances of recreational athletes, the amount of carbohydrate ingested during the day before race-day was identified as a significant and independent predictor of running speed. Furthermore, those runners who ingested more than 7 g carbohydrate per kg body mass during the day before the event ran faster in general and also maintained their running speed to a greater extent than those participants who consumed lower quantities of carbohydrate. This study provides real-world confirmation for the important role of consuming adequate dietary carbohydrate in preparation for prolonged endurance events like the marathon.

Acknowledgements

This study was funded by GlaxoSmithKline. The authors wish to acknowledge the assistance of the organisers of the London Marathon. Sophie L. Mead and Jonathan Sliney (University of Bath, UK) and Dr. Sandra Drummond (Queen Margaret University, UK) are also thanked for their contributions to the project.

References

1 *Ahlborg G, Bergstrom J, Brohult J.* Human muscle glycogen content and capacity for prolonged exercise after difference diets. Forsvarsmedicin 1967; 3: 85–99

2 *Arrese LA, Izquierdo D, Galindo JRS.* Physiological measures associated with marathon running performance in high-level male and female homogeneous groups. Int J Sports Med 2006; 27: 289–295

3 *Atkinson G, Nevill AM.* Selected issues in the design and analysis of sport performance research. J Sports Sci 2001; 19: 811–827

4 *Berg K*. Endurance training and performance in runners – Research limitations and unanswered questions. Sports Med 2003; 33: 59–73
5 *Borg GA*. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982; 14: 377–381
6 *Burfoot A*. The history of the marathon, 1976–present. Sports Med 2007; 37: 284–287
7 *Burke L*. Nutritional strategies for the marathon. Sports Med 2007; 37: 344–347
8 *Burke LM*, *Cox GR*, *Cummings NK*, *Desbrow B*. Guidelines for daily carbohydrate intake – do athletes achieve them? Sports Med 2001; 31: 267–299
9 *Bussau VA*, *Fairchild TJ*, *Rao A*, *Steele P*, *Fournier PA*. Carbohydrate loading in human muscle: an improved 1 day protocol. Eur J Appl Physiol 2002; 87: 290–295
10 *Cheuvront SN*, *Montain SJ*, *Sawka MN*. Fluid replacement and performance during the marathon. Sports Med 2007; 37: 353–357
11 *Coast JR*, *Blevins JS*, *Wilson BA*. Do gender differences in running performance disappear with distance? Can J Appl Physiol 2004; 29: 139–145
12 *Dekkers JC*, *Van Wier MF*, *Hendriksen IJ*, *Twisk JW*, *Van Mechelen W*. Accuracy of self-reported body weight, height and waist circumference in a Dutch overweight working population. BMC Med Res Methodol 2008; 8: 69
13 *Field A*. Discovering Statistics using SPSS for Windows. London: Sage; 2009
14 *Fleg JL*, *Lakatta EG*. Role of muscle loss in the age-associated reduction in VO_2max. J Appl Physiol 1988; 65: 1147–1151
15 *Gorber SC*, *Tremblay M*, *Moher D*, *Gorber B*. A comparison of direct vs. self-report measures for assessing height, weight and body mass index: a systematic review. Obes Rev 2007; 8: 307–326
16 *Hagan RD*, *Upton SJ*, *Duncan JJ*. Marathon performance in relation to maximal aerobic power and training indices in female distance runners. Br J Sports Med 1987; 21: 3–7
17 *Hardy CJ*, *Rejeski WJ*. Not what, but how one feels: the measurement of affect during exercise. J Sport Exerc Psychol 1989; 11: 304–317
18 *Hargreaves M*, *Hawley JA*, *Jeukendrup A*. Pre-exercise carbohydrate and fat ingestion: effects on metabolism and performance. J Sports Sci 2004; 22: 31–38
19 *Harriss DJ*, *Atkinson G*. International Journal of Sports Medicine – Ethical Standards in Sport and Exercise Science Research. Int J Sports Med 2009; 30: 701–702
20 *Hoffman MD*, *Lebus DK*, *Ganong AC*. Body composition of 161-km ultramarathoners. Int J Sports Med 2010; 31: 106–109
21 *Janssen GME*, *Graef CJJ*, *Saris HM*. Food intake and body composition in novice athletes during a training period to run a marathon. Int J Sports Med 1989; 10: S17–S21
22 *Karlsson J*, *Saltin B*. Diet, muscle glycogen, and endurance performance. J Appl Physiol 1971; 31: 203–206
23 *Knechtle B*, *Wirth A*, *Knechtle P*, *Rosemann T*. Training volume and personal best time in marathon, not anthropometric parameters, are associated with performance in male 100-km ultrarunners. J Strength Cond 2010; 24: 604–609
24 *Larsen HB*. Kenyan dominance in distance running. Comp Biochem Physiol A Molec Integr Physiol 2003; 136: 161–170
25 *Levine SA*, *Gordon B*, *Derick CL*. Some changes in the chemicals constituents of the blood following a marathon race. JAMA 1924; 82: 1778–1779
26 *Leyk D*, *Erley O*, *Ridder D*, *Leurs M*, *Rüther T*, *Wunderlich M*, *Sievert A*, *Baum K*, *Essfeld D*. Age related changes in marathon and half-marathon performances. Int J Sports Med 2007; 28: 513–517
27 *Midgley AW*, *McNaughton LR*, *Jones AM*. Training to enhance the physiological determinants of long-distance running performance: Can valid recommendations be given to runners and coaches based on current scientific knowledge? Sports Med 2007; 37: 857–880
28 *Milvy P*. The marathon: physiological, medical, epidemiological, and psychological studies. Ann N Y Acad Sci 1977; 301: 1–1090
29 *Murray B*. The role of salt and glucose replacement drinks in the marathon. Sports Med 2007; 37: 358–360
30 *Noakes TD*, *Lambert EV*, *Lambert MI*, *McArthur PS*, *Myburgh KH*, *Benade AJ*. Carbohydrate ingestion and muscle glycogen depletion during marathon and ultramarathon racing. Eur J Appl Physiol 1988; 57: 482–489
31 *Rapoport B*. Metabolic Factors Limiting Performance in Marathon Runners. PLoS Comput Biol 2010; 6: e1000960
32 *Robert WO*. The 2006 World Congress on the Science and Medicine of the Marathon. Sports Med 2007; 37: 279–280
33 *Rodriguez NR*, *Di Marco NM*, *Langley S*. American College of Sports Medicine position stand. Nutrition and athletic performance. Med Sci Sports Exerc 2009; 41: 709–731
34 *Sherman WM*, *Costill DL*, *Fink WJ*, *Miller JM*. Effect of exercise-diet manipulation on muscle glycogen and its subsequent utilisation during performance. Int J Sports Med 1981; 2: 114–118
35 *Svebak E*, *Murgatroyd S*. Metamotivational dominance: a multimethod validation of reversal theory constructs. J Personality Soc Psychol 1985; 48: 107–116
36 *Utter AC*, *Kang H*, *Robertson RJ*. Effect of carbohydrate ingestion on ratings of perceived exertion during a marathon. Med Sci Sports Exerc 2002; 34: 1779–1784