Predictive Variables of Half-Marathon Performance for Male Runners

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Abstract

The aims of this study were to establish and validate various predictive equations of half-marathon performance. Seventy-eight half-marathon male runners participated in two different phases. Phase 1 (n = 48) was used to establish the equations for estimating half-marathon performance, and Phase 2 (n = 30) to validate these equations. Apart from half-marathon performance, training-related and anthropometric variables were recorded, and an incremental test on a treadmill was performed, in which physiological (VO_{2max}, speed at the anaerobic threshold, peak speed) and biomechanical variables (contact and flight times, step length and step rate) were registered. In Phase 1, half-marathon performance could be predicted to 90.3% by variables related to training and anthropometry (Equation 1), 94.9% by physiological variables (Equation 2), 93.7% by biomechanical parameters (Equation 3) and 96.2% by a general equation (Equation 4). Using these equations, in Phase 2 the predicted time was significantly correlated with performance (r = 0.78, 0.92, 0.90 and 0.95, respectively). The proposed equations and their validation showed a high prediction of half-marathon performance in long distance male runners, considered from different approaches. Furthermore, they improved the prediction performance of previous studies, which makes them a highly practical application in the field of training and performance.

Key words: Running, endurance, training, anthropometry, physiology, biomechanics

Introduction

Long-distance road running races have increased in popularity in the recent years, especially the half-marathon discipline, which has been the distance with the biggest increase in the number of participants (in the United States the number of "finishers" has increased from 482,000 in 2000 to 2,046,600 in 2014) (Running USA, 2015). Not only United States but also European countries, such as Switzerland, have remarkably increased their number of half-marathon runners (from 12,497 in 2000 to 48,061 in 2014) (Anthony et al., 2014; Knechtle et al., 2016). These increased levels of participation have led to an increased range of abilities in runners participating, from amateur to elite levels (Ogueta-Alday and García-López, 2016). Consequently, the interest of the scientific community in studying different factors affecting performance (i.e. anthropometry, training, physiology

and biomechanics) in this discipline has also grown (Ogueta-Alday and García-López, 2016).

The influence of runners' anthropometry on performance has been previously analyzed, and several studies have found negative relationships between half-marathon time and body mass for males (Knechtle et al., 2009; Zillmann et al., 2013), body mass index for females (Hagan et al., 1987) and both males and females (Hoffman, 2008), fat percentage for females (Hagan et al., 1987) and males (Zillmann et al., 2013), lower limbs skinfold sum for both males and females (Arrese and Ostariz, 2006; Legaz and Eston, 2005) and some circumferences of the legs for males (Knechtle et al., 2009). However, the influence of other anthropometric variables such as height is still unclear (Knechtle et al., 2010; Zillmann et al., 2013).

Training characteristics also have a strong influence on performance (Bale et al., 1986; Billat et al., 2003). Thus, male and female elite marathoners run greater distances and at higher speeds during training than lower level runners (Billat et al., 2003), and elite 10,000 m male runners had a greater weekly training volume, a higher training frequency and more years of experience than lower-level participants (Bale et al., 1986). Specific to the half-marathon, one study (Rust et al., 2011) found positive relationships between performance in male runners and various training variables such as weekly distance (kilometers), weekly sessions, average workout speed and weekly training hours. In contrast, another study about female half-marathon runners (Knechtle et al., 2011) only found a correlation between performance and the average speed of training. Therefore, more research is needed to determine the relationship between training and performance, specifically to the half-marathon distance.

The influence of runners' physiological characteristics on performance is well established. Higher values of VO_{2max}, anaerobic threshold and running economy are directly related to performance (Bassett and Howley, 2000; Larsen, 2003). Although a high VO_{2max} is required for high-level competition in long-distance races, a high anaerobic threshold and a good running economy are determinative in runners with similar VO_{2max} (Conley and Krahenbuhl, 1980; Larsen, 2003; Lucia et al., 2006). Specifically, Lucia et al. (2006) observed that, despite no differences in VO_{2max} between male Eritrean and Spanish

runners, Eritreans had a better running economy, allowing them to achieve better performance. Therefore, some studies have shown that the combination of running economy and VO_{2max} could be a good predictor of running performance for males, at least of 3,000 m performance (Storen et al., 2011).

Despite the breadth and depth of knowledge related to running performance in the area of physiology and training, the possible influence of biomechanical variables on long-distance running performance is fairly unclear (Ogueta-Alday et al., 2013; 2014). Previous research has suggested that spatial-temporal parameters (i.e. step rate, step length and contact times) were not related to 3,000 m performance (Storen et al., 2011). However, it appears that experienced runners used a higher step rate than novice ones, which could require less energy expenditure (de Ruiter et al., 2013). Besides, some authors have associated a lower contact time with better performances (Hasegawa et al., 2007; Paavolainen et al., 1999; Santos-Concejero et al., 2013) without considering that contact time depends on both speed and foot strike pattern (Ogueta-Alday et al., 2013; 2014). Therefore, the possible influence of spatial-temporal variables on performance is still an issue of debate.

Predicting performance in long-distance races by equations from some of the above-mentioned perspectives (i.e. anthropometry, training, physiology and biomechanics) has been widely studied (Hagan et al., 1981; Knechtle et al., 2014; Roecker et al., 1998; Rust et al., 2011). Although several recent studies have developed equations for predicting performance in recreational runners which include anthropometric and training variables (Knechtle et al., 2011; 2014; Rust et al., 2011), none of these have been validated in other samples of runners nor do they include physiological or biomechanical variables. Therefore, the two main purposes of the present study were: first, to analyze the relationships between half-marathon performance and anthropometric, training, physiological and biomechanical variables; and second, to establish predictive equations of half-marathon performance using these variables, assessing their predictive accuracy in a different sample of runners.

Methods

Subjects

The study was carried out in two different experimental phases conducted in two different cities with two different runners' populations. All the runners participated in a half-marathon race and performed the same laboratory tests. Participants were volunteers who met the inclusion criteria as follows: Phase 1, runners must have completed during the 6-wk period before the study a half-marathon in less than 105 min, as determined by the official "chip time"; Phase 2 runners had to run a half-marathon in the four weeks after testing.

In Phase 1, 48 male runners participated (age 31.5 ± 7.2 years) and Phase 2 involved 30 male runners (age 34.2 ± 6.8 years) who underwent the same tests. None of the subjects from Phase 1 were included in Phase 2. Anthropometric, training, physiological and biomechanical variables are shown in the Table 1. The protocol was approved by the University Ethics Committee in accordance with the Declaration of Helsinki for human research. The participants were informed of the objectives, practical details and possible risks associated with the experiment, and signed a written informed consent to participate in the study.

Procedures

All data were collected in a single session. Phase 1 was used to establish running performance equations using training, physiological and biomechanical variables to predict half-marathon performance, and Phase 2 was used to validate these equations. First, the subjects were asked about their training-related variables (running experience, weekly training volume and weekly training frequency), and their anthropometrical characteristics were recorded. After this, they completed a standardized warm up of 10 min of running at 10-12 $km \cdot h^{-1}$ on the treadmill, followed by 5 min of self-directed stretching. Second, the participants performed an incremental running test on a treadmill under similar environmental conditions: Phase 1 (~800m altitude, 20-25°C, 20-35% relative humidity) and Phase 2 (~600m altitude, 20-25°C, 45-55% relative humidity). During this test, physiological and biomechanical variables were simultaneously registered. All the participants were instructed on proper hydration and carbohydrate intake prior to testing (Lucia et al., 2006).

Two different and validated treadmills were employed: Phase 1 (HP Cosmos Pulsar, HP Cosmos Sports & Medical GMBH, Nussdorf-Traunstein, Germany) and Phase 2 (ERGelek EG2, Vitoria, Spain). A 1% slope was used to mimic the effects of air resistance on the metabolic cost of flat outdoor running (Jones & Doust, 1996). Respiratory gases were continuously collected with a gas analyzer system (Medisoft Ergocard, Medisoft Group, Sorinnes, Belgium), which was calibrated before each session and verified after each test. Volume calibration and verification were performed following the manufacturer's instructions with a 3 L calibration syringe (Medisoft, Sorinnes, Belgium) allowing an error of ≤2%. Gas calibration and verification were performed automatically by the system (Linde Gas, Germany). Heart rate (HR) was continuously monitored throughout the test (Polar Team, Polar Electro Oy, Kempele, Finland). The biomechanical spatial-temporal parameters of running (i.e. contact and flight times, step rate and step length) were recorded with a contact laser platform installed in the treadmill (SportJUMP System PRO®, DSD Inc., León, Spain) and connected to a specific software (Sport-Bio Running, DSD Inc., León, Spain). This system has been previously validated (Ogueta-Alday et al., 2013).

Anthropometry: Body mass and height were recorded, along with 6 skinfold measurements (triceps, subscapular, supra-iliac, abdominal, anterior thigh and medial calf) using skinfold calipers (HSB-BI, British Indicators LTD, West Sussex, UK). In each phase, all measurements were made by the same researcher following the guidelines of the International Society for the Advancement of Kineanthropometry (ISAK), and the criteria of previous specific studies on runners (Lucia et al., 2006).

Incremental test: The test started at 6 km·h⁻¹ and treadmill speed was increased 1 km·h⁻¹ every 1-min until volitional exhaustion. To be considered a valid test, it was established as a requirement a visible plateau in VO_2 with increasing speeds and a respiratory exchange ratio above 1.15 (Howley et al., 1995). VO_{2max} was defined as the highest 30-s average VO_2 during the test (Fletcher et al., 2009). The respiratory compensation threshold (RCT) was identified according to the criteria of Davis (1985), using different spirometric parameters (i.e. ventilation, VO_2, VCO_2, ventilatory equivalent for VO_2 and VCO_2, end-tidal PCO_2 and PO_2, and respiratory exchange ratio). Spatial-temporal parameters of running were recorded from 10 km·h⁻¹ (i.e. when runners started to exhibit flight time) until peak speed. A minimum recording time of 20 s was set at each running speed to obtain at least 32-64 consecutive steps and thus reduce the effect of intra-individual step variability (Belli et al., 1995).

Statistical analysis

The results are expressed as mean ± standard deviation (SD) values. The Kolmogorov-Smirnov test was applied to ensure a Gaussian distribution of all results. One-way ANOVA was used to analyze the differences between subjects in Phase 1 versus Phase 2. Pearson correlation coefficient (r) was used to obtain relationships between variables. In Phase 1, stepwise multiple-regression analyses were developed to determine half-marathon prediction equations from training-related, anthropometric, physiological and biomechanical variables. In Phase 2, Bland-Altman analysis was used to determine absolute limits of agreement between predicted and race times. SPSS+ version 17.0 statistical software was used (SPSS, Inc., Chicago, IL). Values of $P<0.05$ were considered statistically significant.

Results

Table 1 shows the performance, anthropometric, training, physiological and biomechanical variables of the runners in Phases 1 and 2, and their relationship with race time. Significant differences (p < 0.05) in race time and various anthropometrical, training-related, physiological and biomechanical variables were found between the two groups of runners. On the other hand, in both phases, body mass, body mass index and sum of six skinfolds showed significant relationships with half-marathon performance, while body height did not. Training-related variables also showed significant relationships with performance, and were stronger in Phase 1 than in Phase 2. Physiological variables such as VO_{2max}, percentage of RCT with respect to VO_{2max}, peak speed and RCT speed were significantly related to performance in both phases. Finally, regarding the biomechanical variables, minimum contact time and maximal step length at both peak speed and RCT correlated significantly with performance, while only step rate at RCT in Phase 1 correlated with performance.

The multiple regression analysis conducted with data from Phase 1 determined that the race time could be predicted to 90.3, 94.9, 93.7 and 96.2% (r^2 = 0.82, 0.90, 0.88, 0.93, respectively) by variables related to training and anthropometry (Equation 1), physiology (Equation 2), biomechanics (Equation 3) and a combination of them (Equation 4), respectively.

Table 1. Mean (SD) of half-marathon performance, anthropometric, training, physiological and biomechanical variables of the runners (n = 78) participants in the Phase 1 and Phase 2 of the present study. Correlations to race time ("r").

Variables	Phase 1 (n= 48) Mean (SD)	r	Phase 2 (n=30) Mean (SD)	r
Race time (min)	80.18 (11.33)#		86.66 (8.53)	
Anthropometry				
Mass (kg)	70.2 (6.8)#	.45*	74.9 (11.1)	.52*
Height (m)	1.77 (.06)	-.19	1.78 (.09)	.19
Body mass index (kg·m⁻²)	22.4 (2.0)#	.64*	23.7 (2.1)	.63*
∑ of 6 skinfolds (mm)	51.5 (17.5)	.78*	56.9 (24.0)	.76*
Training				
Running experience (years)	8.8 (6.6)#	-.75*	4.6 (3.1)	-.33
Training volume (km·week⁻¹)	75.7 (36.0)#	-.80*	37.7 (14.8)	-.46*
Training frequency (sessions· week⁻¹)	5.5 (2.4)#	-.83*	3.2 (1.0)	-.45*
Physiology				
VO_{2max} (ml·kg⁻¹·min⁻¹)	61.5 (7.5)#	-.75*	56.5 (6.2)	-.59*
HR_{max} (bpm)	186 (8)	.10	183 (7)	-.05
RCT % VO_{2max}	87.6 (5.2)	-.34*	86.1 (3.1)	-.59*
Peak speed (km·h⁻¹)	19.7 (1.9)#	-.92*	18.9 (1.4)	-.86*
RCT speed (km·h⁻¹)	16.3 (2.1)#	-.92*	14.9 (1.3)	-.92*
Biomechanics				
Minimum contact time (ms)	.207 (.02)	.76*	.201 (.02)	.62*
Maximal step rate (Hz)	3.17 (.16)#	-.04	3.26 (.19)	.05
Maximal step length (m)	1.70 (.18)#	-.73*	1.63 (.14)	-.64*
RCT contact time (s)	.230 (.03)	.82*	.240 (.02)	.65*
RCT step rate (Hz)	2.96 (.15)	-.38*	3.00 (.15)	-.10
RCT step length (m)	1.66 (.20)#	-.87*	1.36 (.13)	-.79*

∑ of six skinfolds, sum of six skinfolds (triceps, subscapular, suprailiac, abdominal, front thigh, and medial calf). VO_{2max}, maximal oxygen uptake. HRmax, maximal heart rate. RCT, respiratory compensation threshold. * Significant correlations with the race time (p < 0.05). # significant differences between both groups (p < 0.05).
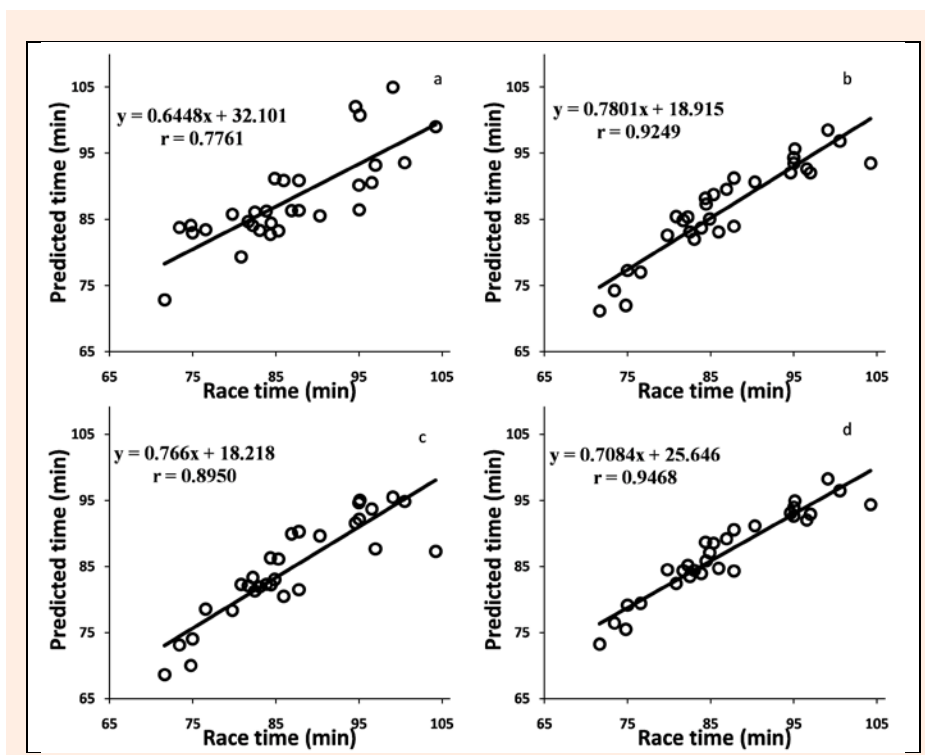
Figure 1. Correlation between the predicted time and the race time in half-marathon for the runners of the Phase 2 (n= 30): Equation 1 (a), Equation 2 (b), Equation 3 (c) and Equation 4 (d).

Equation 1:
- Predicted time (min) = 56.83 – 0.11 weekly training volume (km) – 0.46 running experience (years) + 1.19 body mass index (kg·m^{-2}) + 0.16 sum of six skinfolds (mm)

Equation 2:
- Predicted time (min) = 180.86 – 2.81 peak speed (km·h^{-1}) – 2.77 RCT speed (km·h^{-1})

Equation 3:
- Predicted time (min) = 271.90 – 33.38 RCT step rate (Hz) – 28.38 RCT step length (m) – 29.80 maximal step length (m)

Equation 4:
- Predicted time (min) = 169.54 – 2.51 peak speed (km·h^{-1}) – 2.25 RCT speed (km·h^{-1}) – 0.37 running experience (years)

Figure 1 shows the linear regression analysis performed with data from Phase 2 by using the equations from Phase 1 and the race time. The predicted time significantly correlated ($p < 0.01$) with the race time in all the equations (r =0.78, 0.92, 0.90 and 0.95, respectively).

Figure 2 shows both average systematic bias random error and 95% limits of agreement for Equation 1 (1.51 min, from -9.2 to 12.2 min), Equation 2 (0.14 min, from -6.7 to 6.4 min), Equation 3 (-2.05 min, from -9.7 to 5.7 min) and Equation 4 (0.37 min, from -6.7 to 6.0 min). This last equation (Figure 2d) underestimated the performance of the best runners and overestimated the performance of the lower-level runners.

Discussion

The main outcome of this study was to obtain and validate predictive equations of half-marathon performance in male runners. Most studies have developed predictive equations with a single data collection undertaken prior to the completion of the race (Hagan et al., 1987; Knechtle et al., 2014; Roecker et al., 1998; Rust et al., 2011) or by a pre test-pos test with the same population (Bragada et al., 2010; Stratton et al., 2009; Tolfrey et al., 2009). In this study, the equations were checked in another half-marathon race with a different sample. The proposed equations are good predictors of half-marathon performance, displaying similar or better predictive values than previous studies (Knechtle et al., 2014; Roecker et al., 1998; Rust et al., 2011), and including biomechanical variables, which have not been used in previous studies. Besides, when they were applied in another sample (Phase 2) the correlations with performance were similar or higher than in other studies (Figure 1), with narrowest limits of agreements (Figure 2).

In both phases of the present study, all the anthropometrical variables except the height were significantly related to half-marathon performance (Table 1), which is in accordance with previous studies (Knechtle et al., 2014; Rust et al., 2011). Although some of them have related low height to performance (Loftin et al., 2007; Zillmann et al., 2013), others have not observed any relationship (Hoffman, 2008; Knechtle et al., 2009; 2010). Therefore, according to the results of the present study, no relationship between height and performance in half-marathon runners can be confirmed. Given the positive relationship between body mass, body mass index and
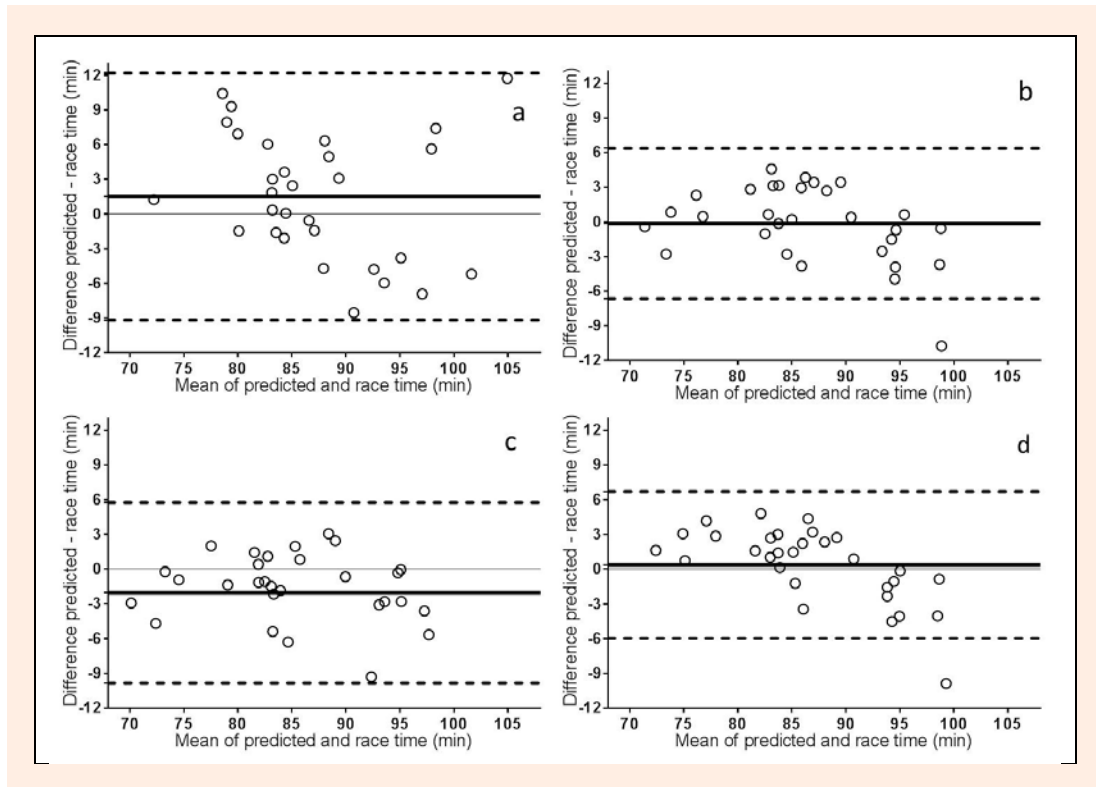
Figure 2. Bland-Altman plots comparing the predicted time and the race time for the runners of the Phase 2 (n= 30): Equation 1 (a), Equation 2 (b), Equation 3 (c) and Equation 4 (2). The short-dashed lines represent the upper and lower 95% limits of agreement, whereas the solid line represents the bias.

sum of 6 skinfolds with running performance, and taking into account that intense training leads to a decrease in skinfolds and consequently body fat (Legaz and Eston, 2005), it is highly advisable to combine the training program with a nutritional plan in order to optimize performance.

Training characteristics (i.e. volume and frequency) were significantly related to half-marathon performance (Table 1), which is in agreement with previous studies (Bale et al., 1986; Billat et al., 2003). However, these relationships were stronger in Phase 1 than in Phase 2, where the years of experience were not related to performance. This could be explained because in Phase 1 participated a higher number of runners with a better level of performance and a wider range of performance levels than in Phase 2 (62.7-100.7 and 71.6-104.2 min, respectively). Although elite runners have more years of experience than lower-level ones (Bale et al., 1986), some studies with recreational runners of homogeneous experience have not found relationships between years of experience and performance in half-marathon (Knechtle et al., 2011; Rust et al., 2011), as occurred in Phase 2.

Similarly to previous studies (Bassett and Howley, 2000; Lucia et al., 2006; Noakes et al., 1990), all the physiological variables except the maximal heart rate were significantly related to race time in both phases, with small differences in between. Peak and RCT speeds were the variables most related to performance, as it has been described in other studies (Noakes et al., 1990; Roecker et al., 1998; Stratton et al., 2009). VO_{2max} and its percentage at the respiratory compensation threshold were worse

predictors of performance, which highlights the need to focus the training on the improvement of peak speed and RCT speed rather than VO_2 variables (Stratton et al., 2009). Interval training, including high intensity interval training (HIIT) would be a good way to improve these capacities and therefore performance (García-Pinillos et al., 2017).

On the other hand, all the biomechanical variables except the step rate were related to performance and showed similar relationships in both phases. Maximal step rate was not related to performance, while RCT step rate only obtained a low correlation with performance in the Phase 1. Some studies found that more experienced and/or high-level runners used a higher frequency to prevent injuries (Gómez-Molina et al., 2016; Schubert et al., 2014; Slawinski and Billat, 2004), and in Phase 1 participated more high-level runners, which could explain this correlation. Maximum step length and RCT step length correlated with performance in both phases and seems to be fundamental to reach high speeds. Therefore, even though more evidence is needed, strength training would be recommended to improve this variable and further running economy (Balsalobre-Fernandez et al., 2016).

Equation 1 (i.e. training and anthropometrical characteristics) showed higher correlations with performance in both phases of the present study (r =0.91 and 0.78, respectively; Figure 1a) than those obtained in previous studies (Knechtle et al., 2014; Rust et al., 2011). Rust et al. (2011) analyzed runners with similar training and anthropometric variables (r =0.63) while Knechtle et al. (2014) also studied male recreational runners (r =0.71).

Furthermore, Equation 1 displayed narrow limits of agreement, from -9.2 to 12.2 min (Figure 2), in contrast to -26.0 to 25.8 min (Knechtle et al., 2014) and -25.1 to 25.1 min (Rust et al., 2011) referred in the abovementioned studies.

Equation 2 (i.e. peak and RCT speeds) also showed high correlations with performance in the present study (r = 0.95 and 0.92, respectively; Figure 1b), similarly to those obtained in previous studies (Bassett and Howley, 2000; Noakes et al., 1990; Stratton et al., 2009). Roecker et al. (1998) found a high correlation between performance of 1,500 m to marathon distances and the individual anaerobic threshold (r = 0.88 to 0.93) and treadmill peak speed (r = 0.85 to 0.91). Another study (Noakes et al., 1990) determined that peak speed and speed at lactate threshold were the best laboratory-measured predictors of half-marathon performance (r = -0.93 and -0.90). Both RCT speed and peak speed appear to be highly significant predictors of performance, possibly because they represent the result of the addition of aerobic and anaerobic capacity.

Equation 3 (i.e. maximum step length, step rate and step length in the RCT) also showed high correlations with performance in both experiments (r = 0.94 and 0.90, respectively; Figure 1c). To the best of our knowledge, this is the first study that uses biomechanical variables to predict half-marathon performance. While some studies found relationships between spatial-temporal parameters and performance (Hasegawa et al., 2007; Hunter and Smith, 2007; Paavolainen et al., 1999) others did not (Kyrolainen et al., 2001; Storen et al., 2011). We do acknowledge that the association between contact time and stride length was provoked by their association with speed as the relationships were not significant when we used running speed as a covariate. Therefore, the association between running contact time and stride length with performance was confounded by the running speed.

Equation 4 (i.e. peak and RCT speeds together to running experience) was the best predictor of half-marathon performance in the present study (r =0.96 and 0.95, respectively; Figure 1d). The mean exercise scope of an athlete is considered the determining parameter besides genetic prerequisites (Roecker et al., 1998). Therefore, the combination of physiological and training parameters seems to be the best combination to predict performance. Hagan et al. (1987) determined another general equation to predict marathon performance in experienced and novice runners (r =0.84) from training-related, physiological variables and physical characteristics: marathon performance (min) = 525.9 + 7.09 (mean km·daily workouts^{-1}) – 0.45 training pace (m·min^{-1}) – 0.17 total km for 9 weeks – 2.01 VO$_{2max}$ (ml·kg^{-1}·min^{-1}) – 1.24 age (years). The present study showed a better prediction, possibly because RCT speed and peak speed were included in the equation instead of VO$_{2max}$. These data indicate that, despite physiological variables being good predictors of time in long-distance running by themselves, their combination with other anthropometric or training relevant variables could further improve the level of prediction.

The high correlations shown by the equations when they were applied in Phase 2 with a second sample (Figure 1), along with the narrow limits of agreement (95%) shown in the Bland-Altman plots (Figure 2), highlights the validity of these equations. In addition, the relatively wide range of performance among runners emphasizes its applicability. Nevertheless, these equations have two mayor limitations. Firstly, high cost equipment is required except for Equation 1, which is very simple to apply. Secondly, the equations were obtained from male runners, and future studies should check their validity in women, since their participation in long-distance races is really growing (Knechtle et al., 2016).

The equations obtained can be a quiet simple tool for teams, coaches and athletes to predict half-marathon performance in male runners. Moreover, considering their accuracy, training paces can be calculated (endurance training paces or high intensity training paces) and race strategy could be set specifically for novice runners. These equations highlight the main variables that could be taken into account during the training process to obtain a high performance in half-marathon races.

Conclusion

In conclusion, the present study obtained four equations involving anthropometric, training, physiological and biomechanical variables to estimate half-marathon performance in male runners. These equations were validated in a different population, demonstrating their consistency. Furthermore, Equation 1 (i.e. training and anthropometrical variables) improved the power of prediction compared to previous studies, while the general equation (Equation 4), which included training and physiological variables (i.e. peak and RCT speeds, and years of experience), provided the best prediction. As a novelty, some biomechanical variables (i.e. step length and step rate at RCT, and maximal step length) have been related to half-marathon performance.

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Key points

- The present study obtained four equations involving anthropometric, training, physiological and biomechanical variables to estimate half-marathon performance.
- These equations were validated in a different population, demonstrating narrows ranges of prediction than previous studies and also their consistency.
- As a novelty, some biomechanical variables (i.e. step length and step rate at RCT, and maximal step length) have been related to half-marathon performance.

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