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Impact of psychological and physiological factors on endurance performance prediction
Impacto de los factores psicológicos y fisiológicos en la predicción del rendimiento en resistencia

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Abstract. Athletic performance is a complex multifactorial phenomenon, therefore several variables should be considered to provide an accurate prediction of time in races. However, physiological variables have usually been used as the main predictors, ignoring the predictive potential of other factors such as psychological variables. The main aim of this study was to provide an equation for predicting performance at 10K, using both physiological and psychological factors as explanatory variables. 13 male runners participated in the study (weight 68.06 ± 18.73 kg; height 174.31 ± 5.39 cm; age 39.5 ± 8.5 years; 57.34 ± 5.03 ml - kg -min VO_{2MAX}). A multiple regression model was established using a stepwise regression approach based on Ordinary Least Squares (OLS). After check possible collinearities, results showed as better predictors of the time at 10K event: $_{V}VO_{2MAX}$ (β=-1.03), Arousal (β=0.17) and Isolation (β=0.19). The resulting regression showed a coefficient of determination (R^2) of 0.98 and RMSE= 50.30 s. $_{V}VO_{2MAX}$ was the best predictor of the 10K performance. However, psychological factors, such as Arousal and Isolation, explain the addition variance. A higher $_{V}VO_{2MAX}$, a lower Arousal and a higher Isolation might allow better athletic performance in the 10K race.
Keywords: Running; modelling; $VO2_{MAX}$; isolation; activation; psychology.

Resumen: El rendimiento en los eventos resistencia es un fenómeno multifactorial complejo, por lo que deben considerarse diversas variables para proporcionar una predicción precisa del tiempo en las carreras. Hasta la fecha se han utilizado las variables fisiológicas como principales predictores, ignorando el potencial predictivo de otros factores como las variables psicológicas. El objetivo principal de este estudio fue proporcionar una ecuación para predecir el rendimiento en 10K, utilizando tanto factores fisiológicos como psicológicos como variables explicativas. Participaron en el estudio 13 corredores varones (Peso 68,06 ± 18,73 kg; Altura 174,31 ± 5,39 cm; edad 39,5 ± 8,5 años; 57,34 ± 5,03 ml - kg -min VO_{2MAX}). Se estableció un modelo de regresión múltiple utilizando un enfoque de regresión por pasos basado en mínimos cuadrados ordinarios. Tras comprobar las posibles colinealidades, los resultados mostraron el $_{V}VO_{2MAX}$ (β=-1,03), Activación (β=0,17) y Aislamiento (β=0,19), como mejores predictores del tiempo en la prueba de 10K. La regresión resultante mostró un coeficiente de determinación (R^2) de 0,98 y RMSE= 50,30 s. $_{V}VO_{2MAX}$ fue el mejor predictor del rendimiento en 10K. Sin embargo, los factores psicológicos, como la activación y el aislamiento, explican la varianza adicional. Un mayor $_{V}VO_{2MAX}$, una menor activación y un mayor aislamiento podrían permitir un mejor rendimiento en la carrera de 10K.
Palabras clave: Carrera; modelización; $VO2_{MAX}$; aislamiento; activación; psicología.

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Introduction

Endurance is defined as the capacity to withstand psychophysical fatigue for a certain period of time (Weineck, 2005). What is more, in endurance sports like in running races, participants need to complete a set distance in the shortest time possible , which is perceived as performance (Ganio et al., 2009; Martínez-Sanz et al., 2020). Sports performance is influenced by the interrelation of different physiological and psychological factors. In this sense, both the functional state and the physical conditions in addition to other external factors influence and determine the competitive results (Clemente-Suárez et al., 2021).

In this sense, physiological factors are the most extensively studied variables associated with performance in endurance sports (Coyle, 1999). These include the following variables: running economy (understood as how efficiently a runner uses oxygen while running at a submaximal speed), lactate/ventilatory thresholds (defined as physiological landmarks representing the shift from primarily aerobic to anaerobic metabolism) , and maximum oxygen uptake (VO_{2MAX}) or $_{V}VO_{2MAX}$ (Tegenge & Melkamu, 2024) representing the minimum velocity needed to elicit VO_{2MAX} (Jones & Carter, 2000).). Other authors also propose variables such as Critical Speed, the fractional use of VO_{2MAX}, the lactate turning point or the resilience (Alvero-Cruz et al., 2020; Jones et al., 2023).

However, VO_{2MAX} and $_{V}VO_{2MAX}$ are among the most frequently measured in sports sciences (Levine, 2008). VO_{2MAX} has been used to partially explain the performance of the cardiovascular system (Bassett & Howley, 2000; Joyner & Dominelli, 2021), establishing a superior limit of energy production in prolonged work. In addition, this factor explains a very high percentage of endurance performance (Evans et al., 1995; McLaughlin et al., 2010), although not all variance. Attending to 10K races, several studies have shown a close relationship between performance at this distance and VO_{2MAX} (Evans et al., 1995; Fay et al., 1989; Kumagai et al., 1982; Meireles et al., 2012; Morgan et al., 1989; Tanaka et al., 1985) although it varies according to the level of the athletes. In this regard, Abad et al. (2016) indicated that there was no relationship between VO_{2MAX} and 10K performance. Additionally, $_{V}VO_{2MAX}$ explains a high percentage of performance, and seems to be decisive when subjects are paired at the same VO_{2MAX} (Meireles et al., 2012; Morgan et al., 1989). Thus, when both subjects have the same values of maximal oxygen uptake, the athlete who displays higher speed at VO_{2MAX} achieves better results (Meireles et al., 2012). A study conducted by McLaughlin et al. (2010) with 17 well-trained runners concluded that the best variable predicting the performance of a 16K endurance test was $_{V}VO_{2MAX}$, compared to VO_{2MAX}, or to the percentage of VO_{2MAX} at the second lactate threshold. Regarding the performance of the 10K race, a relationship was also been found between the time achieved and the minimum speed reached by VO_{2MAX} ($_{V}VO_{2MAX}$) (Meireles et al., 2012, Morgan et al., 1989). A study by Meireles et al. (2012), $_{V}VO_{2MAX}$ also predicted the performance to a large extent, although it was slightly lower than VO_{2MAX}. Thus, both physiological parameters (VO_{2MAX} and $_{V}VO_{2MAX}$) are important for endurance performance.

In addition to the athlete's physiological capabilities, the psychological dimension, such as motivation, should also be considered to improve the explanation of performance (Röthlin et al., 2022; Yendrizal et al., 2024). Previous studies have highlighted that physiological factors do not contribute to explain all variance when endurance performance is predicted when endurance performance is predicted (Evans et al., 1995; McCormick et al., 2015; Keogh et al., 2019; Alvero-Cruz et al., 2020). Therefore, the psychobiological endurance model might better explain the influence of these variables on sports performance than one of them alone (Röthlin et al., 2022). Thus, psychological factors influence endurance performance, according to the psycho-biological model of endurance (Marcora, 2008), an effort-based decision-making model based on motivational intensity theory. The model suggests that perception of effort and prospective incentive are the main factors influencing conscious pace management. Considering this model, athletes will stop their endurance activity when the effort required by the work exceeds the highest effort the individual is willing to make and they find it impossible to continue the activity (Marcora & Staiano, 2010). In this context, the main factor limiting endurance performance is the perception of individual effort (Blanchfield et al., 2014). Consequently, any physiological or psychological factor that influences this perception of effort may affect endurance performance (Marcora et al., 2008). Thus, factors such as motivation, or use of mental techniques such as self-talk, goal setting, arousal or imagery, could affect endurance performance (Gould & Udry, 1994; McCormick et al., 2015, Taylor et al., 2020; Wallace et al., 2017; Kurniawan et al., 2023).

The first factors that could influence endurance performance are mental techniques, including self-talk, arousal regulation, imagery, and goal-setting. In this regard, self-talk refers to what the athlete says to himself/herself loudly, silently, automatically, or strategically, to correct, stimulate, or evaluate the action (Hatzigeorgiadis et al., 2011), and is one of the most practical strategies for improving athletes' performance. Moreover, it also helps athletes to increase their motivation or focus on sports tasks (Van Raalte et al., 2016). The use of motivational self-talk improves time-trial performance during cycling, displaying higher levels of power (Barwood et al., 2015). Wallace et al. (2017), conducted a motivational self-talk intervention with cyclists for two weeks showing increase on performance during a maximal cycle ergometer test in heat conditions (35ºC). These authors concluded that motivational self-talk not only increased performance, but also helped to tolerate heat much better. Finally, it can be stated that self-talk can be a powerful tool to improve the confidence, motivation and performance of athletes, especially positive or motivational self-talk (Blanchfield et al., 2014; Winberg et al., 1984; Basset et al., 2022).

Arousal is another psychological factor that is related to sports performance. This factor is defined as a cognitive and somatic reaction to an internal or external stimulus (Birrer & Morgan, 2010). What is more, it refers to the overall combination of physical and mental level of activity that a person feels, which can range from being in a deep sleep to feeling extremely excited (Wesson et al., 2000). There is an optimal state of arousal for each athlete to reach the maximum level of performance (Birrer & Morgan, 2010). However, this differs according to variables such as situational factors, a combination of cognitive and affective sensations (Hardy et al., 1996), the demands of the sport, and personal preferences (Hanin, 2000). Scientific evidence indicates that techniques that regulate arousal serve to manage stress, arrive at competition in an optimal mental state, and thus, increase performance (Gould & Udry, 1994). However, contrary to this evidence, in a recent study by Röthlin et al. (2022) in which the influence of different psychological and physiological variables on performance was analyzed, arousal was not related to improvement in performance. There is still a need for research on the materialization of this regulation "when", "with whom" and "how".

In turn, imagery or visualization, which is referred to as the creation or recreation of experiences created from the subject's memories or information in memory, might influence athletes' performance (Simonsmeier et al., 2021). Specifically, in endurance sports, several studies have shown that using visualization technique training improves performance in swimmers (Post et al., 2012) and runners (Spino & Straub, 2014).

Another widespread mental technique used by athletes is goal setting. Locke and Latham (2002) developed the theory of this psychological factor. Through this theory, the authors explained that objectives directly influence the individual's attitude. Athletes use process and/or performance goals to focus on the athletic task, among others (Weinberg & Butt, 2014). In this study, which was conducted with amateur marathoners, experienced runners were asked about their target running time while other experienced runners were not and first ones ran faster than unasked marathoners (Sackett et al., 2014). This made their goals more ambitious and improved their performance. On the other hand, in a study that was conducted with five university students aged 18-28 years, it helped them to increase the distance they ran per week, i.e. to set short and long term goals, they increased their weekly running time (Wack et al., 2014). Regard to psychological variables, motivation is another important factor that might affect endurance performance. Motivation refers to the process of initiating and maintaining goal-oriented activities (Cook & Artino, 2016). Besides, motivation refers to the direction and the intensity of the effort that a person does (Sage, 1977); direction of effort refers to what an individual is attracted to (i.e. winning a race) and intensity refers to how much effort a person is disposed to do to achieve a goal (Morgan and Sproule, 2012). Vallerand and Thill (1993) analyzed motivation in the sports environment and defined it as any internal and external force that gives initiation, direction, intensity, and persistence to both an individual attitude and an action. Among university athletes, autonomous or intrinsic motivation showed a close relationship with perception, sport satisfaction or sport performance to achieve goals. Therefore, this variable seems to be a determinant in different sports fields, not only in high performance (Vallerand & Till, 1993). In addition, motivational patterns improve performance in middle-distance running (Donohue et al., 2006; Miller & Donohue, 2003) and appear to be related to athletic ability in intermittent sports (Zuber & Conzelmann, 2014).

Finally, self-compassion is one of the most important psychological determinants of success that athletes can aspire to and that athletes perceive as limiting or necessary when working towards their goals or expectations, although the relationship between this psychological variable and sports performance is complex (Adam et al., 2021). Self-compassion is understood as the recognition of one's own suffering and the desire to alleviate it, offering protection, in this case to the athlete, from maladaptive psychological experiences in sport (Cormier et al., 2023). That is, self-compassion would include being kind and understanding with oneself, as well as the desire to achieve one's own well-being and not adopting a self-critical stance with one's perceived shortcomings and weaknesses in oneself. (Röthlin et al., 2019). In terms of sport performance, in major competitions, such as territorial or international competitions, women, for example, use self-compassion to foster perceptions of performance and well-being when training and competing (Killham et al., 2018). Some athletes recognise that self-compassion reinforces perseverance to overcome difficulties, which, as discussed above, might improve performance through psychological pathway (Ferguson et al., 2014). In contrast, in a study conducted with subelite cyclists, there was no direct relationship with endurance performance (Röthlin et al., 2022).

Hence, although physiological factors such as VO_{2MAX}, $_{V}VO_{2MAX}$ or lactate threshold have been studied extensively (Jones & Carter, 2000; Bassett & Howley, 2000; Joyner & Coyle, 2008), psychological factors have received less scientific interest. For this reason, even athletes recognize that psychological factors influence their performance, attempts to predict it considering both dimensions are limited in scientific literature (Röthlin et al., 2022). However, these have often been investigated independently of physiological factors (Morgan et al., 1989; McCormick et al., 2015; Barwood et al., 2015; Billat et al., 2001; Jones, 2006; Jones et al., 2021). Consequently, the main aim of this study was to analyze whether psychological factors influence performance or contribute to higher performance in 10K race, taking into account individual physiological factors. To conduct this study, the work of (Röthlin et al., 2022) was used as a reference. Finally, our hypothesis was that the inclusion of psychological and physiological factors would significantly improve the predictive accuracy of the regression model compared with the use of physiological variables alone.

Materials and methods

Design and Participants

The present study followed a retrospective design. The inclusion criteria for this study were as follows: (I) training and competing experience as an athlete (> 5 years practicing this sport), (II) running more than 3 days a week for 45 min, and (III) not being injured at the time of the study. Once the inclusion criteria were considered, 13 male runners participated in the study (weight 68.06 ± 18.73 kg; height 174.31 ± 5.39 cm; age 39.5 ± 8.5 years; 52.18 ± 16.22 ml - kg - min VO_{2MAX}). All participants provided a medical check-up and signed an informed consent form before participating in the study. This study was approved by the Ethics Committee of the Department of Physical Activity and Sport Sciences (Reference: ETK-52/21-22) and was conducted in accordance with the Declaration of Helsinki. The performance of the samples was classified according to the criteria of McKay et al. (2022). To differentiate trained/developed and national-level athletes according to this classification, the minimum marks established for national championships in 2022 were consulted (Real Federación Española de Atletismo, 2023). In this study, 12 runners in the sample were trained/developed, and one runner was a national-level runner.

Measures

Data collection took place over two days, the first day was conducted in the laboratory, where a graded exercise protocol (GXP) was performed. The second day was the race day (10K Villa de Laredo), one of the fastest races at both national and international level, where the second fastest World Time has been made (World Athletics, 2023). On the morning of the race day, participants completed a questionnaire to measure psychological factors, and in the afternoon, they completed the race. The race time was collected as a performance indicator. Running time in the previously mentioned race was taken as the dependent variable, while psychological variables, VO_{2MAX} and $_{V}VO_{2MAX}$ were independent variables.

Physiological measurements were carried out 6 days before or 10 days after the race, minimizing the interference effect between them. Subjects were advised to; (I) avoid any type of intense sports activity (RPE >7/10) 48h prior to the measurement, (II) eat a carbohydrate-rich meal and maintain hydration ad libitum both on the day of the measurement and the day of the race, (III) do not take performance-enhancing supplements on the day of the laboratory and wear competition shoes.

The participants completed the GXP running test until volitional exhaustion. The warm-up of this test started with walking for 5 min, without exceeding 60% of the maximum heart rate, according to Tanaka's protocol (Tanaka et al., 2001). The test was initiated at 8 $km.h^{-1}$ and the intensity was increased by 0.3 $km.h^{-1}$ every 30 s (Esteve-Lanao et al., 2007). During the test, athletes were verbally encouraged. A chest strap (Polar, Kempele, Finland) was used to record heart rate. The incremental running test was performed on a Medisoft 870s SPORT treadmill (Ergometrix, RAM 870s, Barcelona, Spain) with a 1% incline, compensating for air resistance (Jones & Doust, 1996). Finally, the Ergostik gas analyzer was used (Geratherm Respiratory GmbH, Bad Kissingen, Germany) to record VO_2 and $_VVO_2$ and calculate ventilatory thresholds.

$_VVO_{2MAX}$ was determined as the minimal velocity eliciting the VO_{2MAX} uptake, or in cases there was no clear $_VVO_2$ plateau, as peak velocity was obtained for the last complete 30 seconds stage. At least, two of the following criteria were required for the attainment of VO_{2MAX}: a plateau in VO_2 values (i.e. an increase in VO_2 between two or more consecutive stages of less than 1.5 $ml.kg^{-1}.min^{-1}$ (Esteve-lanao et al., 2007), a respiratory exchange ratio value ≥ 1.15, or the attainment of a maximal HR value (HR max) above 95% of the age-predicted maximum (207 - 0.7 x age) (Gellish et al., 2007).

Different validated questionnaires were used to measure the psychological factors. Motivation was measured with the 20-item *"Cuestionario de Motivación en el Deporte"* (CMD) (González et al., 2015). The response scale is a Likert-type scale where the questions begin with "I practice sport..." and the answers range from one to five. On this scale, 1 corresponds to "I strongly disagree" and 5 to "I strongly agree". This questionnaire consisted of 20 items (e.g., Because it is fun), through which the sub-factors intrinsic, internal, identified, external, and de-motivation were measured. The CMD sub-factors intrinsic, identified, introjected, extrinsic motivation and demotivation, α = .74, α = .68, α = .92, α = .95 and α = .08, respectively.

After this, the Spanish adaptation of the *"Test of Performance Strategies 3"* (TOPS-3) (Lourido et al., 2018) was used to measure the use of Mental Techniques. The test consisted of 36 items. Responses were recorded on a Likert scale: 1. never; 2. seldom; 3. sometimes; 4. often; 5. almost always. This questionnaire measures nine sub-items, including questions such as "I set specific goals during competition" or "I evaluate whether I achieve my competitive goals". In the TOPS-3 questionnaire, Cronbach's alpha values were as follows: attentional-control: α = .84, emotional control: α = .83, automaticity: α = .82, goal setting: α = .87, visualization: α = .89, activation/arousal: α = .73, relaxation: α = .83, attention control: α = .79 and negative thinking: α = .69.

Finally, the Spanish version of the "*Self-Compassion Scale*" (SCS; Neff, 2003) was used to measure self-compassion (García-Campayo et al., 2014), which was analyzed using 26 items. This questionnaire uses a 5 Likert scale, with responses ranging from 1, "Almost never", to 5, "Almost always". Five sub-factors were measured using the questionnaire: self-kindness, humanity, self-judgment, isolation, and over-identification. Examples of items are: "I disapprove of my own faults and inadequacies and am critical of them" or "I am tolerant of my own faults and imperfections or weaknesses". To calculate the total value of the questionnaire, the inverse scores of the items of the negative subscales of self-judgment, isolation, and over-identification should first be calculated (i.e., 1 = 5, 2 = 4, 3 = 3. 4 = 2, 5 = 1). For the SCS questionnaire, α = .75, α = .58, α = .63, α = .72 and α = .77 values were obtained for the sub-factors of self-kindness, humanity, self-judgment, isolation and over-identification.

Statistical analysis

The normal distribution of continuous variables was checked using the Kolmogorov-Smirnov, Cramer-Von Mises, and Anderson-Darling tests. A multiple regression model was used to predict the final time at 10K (the dependent variable). The following independent variables were considered possible predictors of 10K time: $_VVO_{2MAX}$, $_VVT1$, $_VVT2$. VO_{2MAX}, motivation (intrinsic, extrinsic, introjected, identified), use of mental techniques (arousal, imagery, goal setting, self-talk, emotional control, automaticity, relaxation, negative-thinking, visualization, attentional-control, self-kindness), self-compassion (common humanity, self-judgment, isolation, self-kindness, overidentification). Owing to the low reliability of the questionnaire results, the demotivation factor was eliminated.

Multicollinearity analysis was performed to avoid bias in the interpretation of regression coefficients. Therefore, a correlation matrix between the independent variables was set prior to the regression analyses. A Pearson correlation coefficient > 0.8 was associated with the likelihood of collinearity, as previous studies have suggested (Vatcheva et al., 2016; Shrestha et al., 2020). Thus, if a high correlation coefficient was observed between the variables (R^2 >0.8), one was removed.

After this preliminary test, almost all the independent variables were considered in the regression model. The explanatory variables $_VVT1$ and $_VVT2$ were removed because of their high correlation with $_VVO_{2MAX}$ (R^2 > 0.8). For the final regression model the best explanatory independent variables were selected using a stepwise regression approach based on the Ordinary Least Squares (OLS), for performing this analyzes R's package *olsrr* (Hebbali, 2023) was used.

The R package dplyr was used to identify possible outliers and improve the fitting of the regression model

(Wickham et al., 2023). No outliers were identified after this analysis. After the outliers detection and stepwise test, the final regression model was considered predictable variables: isolation, arousal and $_{V}VO_{2MAX}$. For internal validation, a k-fold cross-validation (10 folds and five repetitions) was performed. Internal validation was performed to reduce possible overfitting of the model (Bullock et al., 2021).

The assumptions of the final regression were checked (skewness, kurtosis, nonlinear link function, and heteroscedasticity). To check whether the prediction of the final model and the real time in the 10K race could differ significantly, a comparison analysis (Bland-Altman) was conducted. The root mean square error (RMSE) and R^2 and R^2 Adj. were used to evaluate the performance of the model. Model error is expressed in outcome units (i.e., seg). The significance level for each two-sided statistical analysis was set at *p* 0.05. R software version 4.2.2 (R Core Team, 2022) and RStudio version 2022.12.0.353 (Rstudio Team, 2022) were used for the statistical analysis.

Results

Table 1 shows means and standard deviations for race time (endurance performance), VO_{2MAX}, $_{V}VO_{2MAX}$ and all psychological variables examined.

Stepwise regression analysis was suggested as the principal predictors of the dependent variables $_{V}VO2_{MAX}$, isolation, and arousal. The most important predictor of the regression model (Table 2) was $_{V}VO_{2MAX}$; for each km•h^{-1} improvement, the time in the 10 K race decreased 2:09 [min:s]. Conversely, greater arousal leads to poorer running performance. Specifically, for every one unit increase in this variable, the time spent by the athlete increases by almost 53 seconds. In turn, an increase in the isolation variable leads to worse performance. For each point increase in this variable, performance in competition will worsen by approximately 43 seconds.

Table 1.
Variables studied with their mean and standard deviation.

Variable	Mean	Standard deviation
$_{V}VO_{2MAX}$ (ml · kg · min^{-1})	17.69	1.49
VO2MAX	57.34	5.03
Race time (s)	2276.23	202.59
Intrinsic motivation[1]	4.53	.37
Extrinsic motivation[1]	1.88	1.06
Introjected motivation[1]	3.13	1.31
Identified motivation[1]	4.01	.67
Arousal[2]	3.78	.66
Imagery[2]	2.65	.58
Goal setting[2]	4.25	.35
Self-talk[2]	3.36	.85
Emotional Control[2]	3.98	.81
Automaticity[2]	3.61	.77
Relaxation[2]	1.98	.99
Negative-thinking[2]	3.01	.85
Visualization[2]	2.65	.58
Attentional-Control[2]	4.38	.49
Common humanity[3]	3.01	.72
Self-Judgment[3]	3.43	.70
Isolation[3]	3.94	.88
Overidentification[3]	3.51	.90

Note. $_{V}VO_{2MAX}$: Velocity at maximal oxygen uptake. VO_{2MAX}: maximal oxygen uptake. s: seconds. [1]: item belonging to the CMD questionnaire. [2]: item belonging to the TOPS-3 questionnaire. [3]: item belonging to the SCS questionnaire. All psychological items are represented in a 1- 5 point Likert scale.

Table 2.
Regression results using 10K time as the criterion.

	b		beta		sr^2		
Predictor	b	95% CI [LL, UL]	beta	95% CI [LL, UL]	sr^2	95% CI [LL, UL]	r
Intercept	4371.02**	[3995.78, 4746.25]					
$_{V}VO_{2MAX}$	-139.25**	[-161.24, -117.25]	-1.03	[-1.19, -0.86]	.90	[.66, 1.15]	-.94**
Arousal	52.98*	[1.62, 104.35]	0.17	[0.01, 0.34]	.02	[-.02, .07]	-.16
Isolation	42.63*	[6.94, 78.33]	0.19	[0.03, 0.34]	.03	[-.02, .08]	.13

Note. $_{V}VO_{2MAX}$: Velocity at maximal oxygen uptake. A significant b-weight indicates the beta-weight and semi-partial correlation are also significant. b represents unstandardized regression weights. beta indicates the standardized regression weights. sr^2 represents the semi-partial correlation squared. r represents the zero-order correlation. LL and UL indicate the lower and upper limits of a confidence interval, respectively.
* indicates p < .05. ** indicates p < .01.

The cross-validation analysis showed very high accuracy and internal validity of the present model (R^2=0.98 and RMSE= 50.30 s). Comparison analysis did not show significant differences between the prediction outcome and real time in the 10K race (t= 0.008; 95% CI [-78.92-79.10]; p > 0.05) (Figure 1).

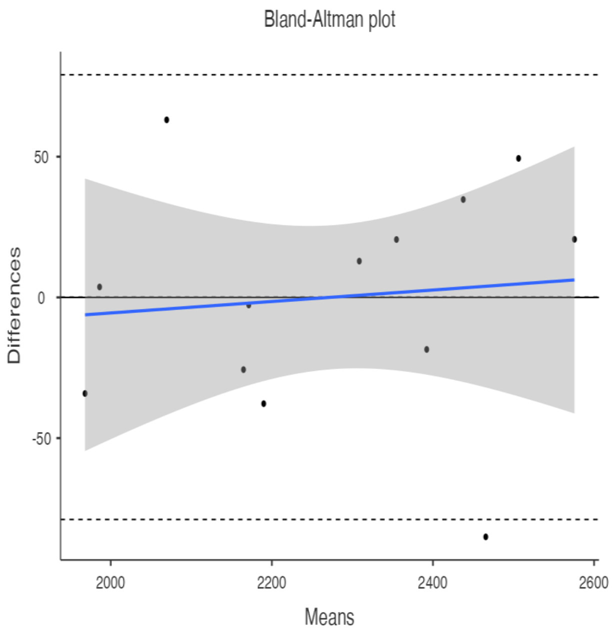

Figure 1. Bland–Alman plot for the differences between the real 10K time and predicted.

The predictive equation for the model is showed in the Table 3.

Table 3.
Equation for estimating time in a 10K

Race time (ins) = 4371.02 – 139.25 · ($_V$VO$_{2MAX}$) + 42,63 · (Subject's isolation level) + 52.98 · (Subjects arousal level).

Discussion

The main objective of this study was to analyze the influence of psychological and physiological factors on endurance performance. Our results indicate that 10K performance time is highly dependent on physiological variables (in this case, $_V$VO$_{2MAX}$). However, psychological variables (arousal and isolation), although to a lesser extent, help determine time in a 10K race, which confirms our hypothesis. As it is known, several studies relate endurance performance to the physiological factors of runners (Jones, 2006; Jones et al., 2021). The inclusion of psychological variables in the model improved accuracy more than the inclusion of physiological variables alone.

Regarding the physiological factors, the variable with the highest predicted performance was $_V$VO$_{2MAX}$. These results are consistent with those of previous studies, particularly regarding the relationship between $_V$VO$_{2MAX}$ and 10K running time (Meireles et al., 2012; Morgan et al., 1989). This value reflects the minimum speed necessary to elicit VO$_{2MAX}$, which is an indicator of aerobic and cardiovascular capacity. Furthermore, the contribution of aerobic metabolism to 10K race has been reported to be greater than 95% (Sandford & Stellingwerff, 2019), underlining the importance of oxidative pathways.

Previous research has shown that VO$_{2MAX}$ is closely related to 10K performance (Evans et al., 1995; Fay et al., 1989; Kumagai et al., 1982; Meireles et al., 2012; Morgan et al., 1989; Tanaka et al., 1986). Even in other studies VO$_{2MAX}$ appeared to be a better indicator of aerobic capacity and athlete level; in this case, it did not contribute more to the prediction models than $_V$VO$_{2MAX}$. To understand this fact, it is necessary to analyze the mean age of the sample of our study (39.5 ± 8.49). One plausible reason for the difference between our study and previous studies could be partially explained by the decrease in VO$_{2MAX}$ with age (Tanaka et al., 1986). Therefore, by analyzing the mean age of other studies, which was lower than our sample (Evans et al., 1995; Fay et al., 1989; Kumagai et al., 1982; Morgan et al., 1989; Tanaka et al., 1986), this could explain partially these differences. Therefore, and considering that an indirect estimation of $_V$VO$_{2MAX}$ is easy to perform and its great ability to determine performance in a 10K race (Table 2), an estimation by a simple field test, with a small expenditure of time and without the need for expensive materials, can help the athlete or coach to determine with great accuracy the athlete's future performance.

Regarding psychological factors, isolation was the second most important variable in the model. To the best of our knowledge, no study has yet examined the relationship between these two variables. One of the few studies that have analysed the impact of psychological factors on sport performance is the one published by Röthlin et al. (2022), although isolation was not one of the selected psychological variables. By analyzing the isolation items, this study found that lower isolation increased performance. This may be because the athlete focuses only on himself; he puts all positive and negative thoughts on him. This may cause him to pay all his attention to himself or herself, seeking a state of perfectionism, disregarding the problems and feelings of others, and dissociating them from the world, which could negatively influence individual performance. However, mechanistic studies are needed to study the cause-effect relationship between isolation and sports performance.

The last variable that helped predict performance was arousal. In our study, a higher arousal level elicited a better performance. This could be because there is a need for a minimum level of somatic and cognitive activation to perform motor tasks. However, as explained previously, a recent study showed that this variable did not explain performance among cyclists, which differs from our results (Röthlin et al., 2022). Although theories of the optimal arousal model have been extensively developed, very few studies have related it to sports performance (Hanin, 2000; Rainer et al., 1990; Robazza et al., 2004). In addition, Yerkes and Dodson (1908) stated that extremely high or extremely low levels of arousal could negatively affect performance, whereas optimal performance could be achieved with moderate levels of arousal. Thus, more research is needed to understand the relationship between arousal level and performance in endurance sports. To finish with, taking into account that it may influence performance, the implementation of psychological training for achieving the optimal individual level of arousal could be an interesting tool for enhancing sport performance.

Previous studies have attempted to predict performance in 10K races by providing prediction models using only physiological factors. Most of those provide an R^2 between 0.60 and 0.80 (Alvero-Cruz et al., 2020), which are lower than those obtained in the present study ($R^2 = 0.96$). The best prediction models have achieved similar values ($R^2 =$ 0.96/0.94/0.86, in Tanaka (1984) and Petit et al. (1997); Fay et al. (1989) and Bale et al. (1986), respectively) but did not provide information for the prediction equation or with higher standard errors. Thus, it is worth noting that the implementation of psychological factors can improve the predictive ability of models in a similar sample. What is more, all of them require the use of high cost instruments (metabolic carts, lactate analysers, or skinfold callipers) (Alvero-Cruz et al., 2020). Recently, protocols have been published (such as 1500m gun-to tape time trials) to obtain $_{V}VO_{2MAX}$ derived from incremental tests (Sandford et al., 2019). Therefore, it is important to highlight the applicability of our findings in comparison to the existing literature, due to the necessity of a small amount of material and resources (1500m test and psychological questionnaires) to estimate 10K performance in trained subjects, a large part of the global population (~12%–19%) (McKay et al., 2022).

Limitations

Although innovative findings were obtained, the authors are aware of several limitations. First, the sample size (n = 13) limits the generalizability of the results and reduces statistical power. Second, the results of this study are applicable to "trained/developed" male runners, not to elite or international athletes or lower-level athletes, which should be taken into account from a performance point of view because its determinants may be different between levels. Similarly, few women initially volunteered to participate in the study and meet the requirements, but since they did not complete the race, they are not included in the sample. Besides, this limitation must be taken into account since the results of this research would be extrapolable only to trained/developed male runners according to the classification of Mckay et al. (2022). Finally, the prediction model has a standard deviation of 46.5 seconds (4.65 sec/km). Therefore, if the formula obtained is used to establish the running pace, other variables, such as the previous 10K pace or the physical condition of the athlete, among others, would have to be considered.

Conclusion

Through this study, we can conclude that in trained/developed runners, 10K performance can be explained by physiological variables to a large extent, but psychological variables (isolation and arousal) also help predict performance. As these constitute a high percentage of the population, they are applicable to a large part of the sector and offer low-cost alternatives to laboratory tests.

Our regression model may allow coaches and runners to predict their 10K running performance using questionnaires and field tests. Furthermore, this method of predicting the running time does not require complex materials to carry out the calculation, all of which are easily accessible.

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