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Contribution of Nutrition and Psychometric Factors to the Fatigue Component of a Performance Prediction Model in Endurance Running

Emily Baker[1], Colin Solomon[2,3,*], Ian Stewart[1]

[1]Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia
[2]School of Life Sciences, Queensland University of Technology, Brisbane, Australia
[3]School of Health and Sport Sciences, University of the Sunshine Coast, Sippy Downs, Australia
*Corresponding author: csolomon@usc.edu.au

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Abstract Mathematical models can be used to predict exercise performance, but the specific factors contributing to the fatigue component of these models are unknown. This study was designed to determine the contribution of nutrition and psychometric factors to the fatigue component of a performance prediction model for endurance running. It was hypothesized that there would be a positive correlation between both nutritional intake and psychometric factors, and the modeled fatigue. One experienced male marathon and ultra-marathon runner was monitored during 18-weeks of training, involving a weekly performance test (mean ± SD; distance = 10508 ± 113 m), nutritional diaries, and psychometric questionnaires (POMS and RESTQ-Sport). A dose-response based model incorporating two antagonistic components, fitness and fatigue, and training data, was used to calculate modeled performance, which was correlated against actual performance. The performance fit was low (r^2 = 0.24, P = 0.05) when modelled for the total 122 day period, however the fit was increased when the model was divided into two separate training periods (days 1 - 66: r^2 = 0.55, P = 0.02; days 66 - 122: r^2 = 0.87, P = 0.002). There were significant (P <0.01) positive correlations between modelled fatigue and the nutritional data (Fat r^2 = 0.78), POMS (Vigour r^2 = 0.92), and RESTQ-Sport (General Recovery r^2 = 0.74; Sports Recovery r^2 = 0.71; Global Recovery r^2 = 0.78). The results indicate a high correlation between nutritional intake and scores on the psychometric questionnaires, and the fatigue parameter of the model. Therefore, these factors should be measured and used in models of fatigue.

Keywords: *fatigue, performance, endurance, model*

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1. Introduction

In order to enhance the understanding of the association between training and performance, a systems model was developed to predict performance where training represented the dose and a change in performance represented the response [1]. This dose-response relationship uses the two antagonistic components, fitness and fatigue, to calculate performance-based on training data. Training is quantified according to the athletic discipline then entered into the model. The model employs fixed equations incorporating constants, unique to the individual that determines the rate of accumulation and decay of both fitness and fatigue, to determine the performance outcome. The pattern between these hypothesized components becomes a valid representation of the real time course when a significant correlation exists between actual and modeled performance [2].

To bring physiological meaning to what is currently a black box strategy, modeling research has attempted to explain the fitness and fatigue components of performance predicting models [1-10]. The complexity and longitudinal format of this type of research have meant the majority of studies have involved small sample size [3,6,7,8] or case study approaches [1,2,4,5,9,10]. To date, success has only been reported for the fitness component, whereby running speed at the ventilatory threshold explained 88% of the variance in modeled fitness in an endurance runner [10]. The fatigue component has also been investigated previously, with biological indices such as elevated serum enzyme activity [2], iron [3] and testosterone [6] providing limited success, mostly due to the differences in the timing of the changes in these indices as a result of training.

It is established that nutrition plays a pivotal role in athletic performance and the attenuation of fatigue. Carbohydrate, in particular, is important for an endurance athlete, as adequate consumption can delay the onset of fatigue during prolonged exercise [11]. Carbohydrate is an essential intermediary for the oxidation of fat and these are the preferential energy sources for extended aerobic exercise [12,13]. The association between nutrition and fatigue has been referred to in many overtraining and performance modeling studies [1,14,15,16] however this has never been investigated in detail.

The use of psychometric questionnaires in the assessment of fatigue has also been investigated [10,17], with mixed results. The use of questionnaires has shown utility, with the Fatigue scale of the Profile of Mood States (POMS) explaining 54% of the variance in modeled fatigue for an endurance runner [10]. It was proposed that the ability of psychometric questionnaires to include fatigue unrelated to training was the primary factor in this result.

Therefore, whilst mathematical models can be used to predict exercise performance, the specific factors contributing to the fatigue component of these models are unknown. The specific aim of this study was to determine the contribution of nutrition and psychometric indices to the fatigue component of a performance predicting model, in endurance running. It was hypothesized that there would be a positive correlation between the modeled fatigue and both nutritional intake and psychometric scores.

2. Methods

2.1. Participant

The participant was one healthy 44-year-old male, experienced (20 years of training and competition) competitive, endurance (5 - 100 km events) runner. The participant gave informed consent, and the study was conducted according to the principles of the Declaration of Helsinki.

2.2. Design

The participant was monitored during 122 consecutive days of training and competition. During the monitoring period the participant was training for and competed in a half-marathon event (Day 37), a marathon event (Day 65) and a 96 km team event (Day 78). On a weekly basis, he completed a performance test, 3-day consecutive food record and two different psychometric (fatigue) questionnaires. The performance tests and questionnaires were carried out at the same time of day, on the same day of the week, as practical. On a monthly basis, a treadmill fitness test was conducted the day after the performance test. Total daily energy expenditure was estimated from 24-hour heart rate records undertaken on two separate occasions.

2.3. Training

The participant performed his usual, self-prescribed and monitored training programme. Training times and heart rate were recorded by a heart rate monitor (Forerunner 405 CX, Garmin, Kansas, USA), and downloaded to internet based computer software (Garmin Connect, http://www.connect.garmin.com).

2.4. Performance Test

The participant completed a 10508 ± 113 m time trial once a week. The trial was conducted on two courses due to the participant travelling overseas in weeks 14-18. It was suggested by the developers of the model that the performance test have a major emphasis on the specific fitness component of the chosen discipline, yet require minimal skill [18]. Therefore 10000 m was chosen as this was considered, the distance with the highest aerobic energy system contribution that could be completed comfortably on a weekly basis. Performance times and heart rate were recorded as previously mentioned. Performance times were converted to an average speed, to accommodate the slightly different distances of the two courses, then linearly, to a criterion point score out of 1000, relative to the best performance achieved by the participant in the previous year [19].

2.5. Diet Record and Analysis

The participant completed a three-day weighed food record, using household measures for three consecutive days, comprising the day of the performance test and the subsequent two days, covering two weekdays and one weekend day every week when possible. All food diaries were analysed using a dietary software program (Foodworks Professional Version 4.00, Xyris Software, Australia).

2.6. Psychometric Questionnaires

The Profile of Mood States (POMS) consists of a 5-point scale (0 - ‘not at all’ to 4 - ‘extremely’) which the participant uses to rate a question in relation to “how have you been feeling for the past week including today?” The heading was changed to ‘in the past three (3) days/nights’ to match the reference time of the Recovery Stress Questionnaire for Athletes (RESTQ-Sport) [20]. A global measure of mood was determined from summing the five negative mood states (tension, depression, anger, fatigue and confusion) and subtracting the only positive mood state (vigour) and adding 100 to avoid negative scores [16].

The RESTQ-Sport was set out with a Likert-type scale ranging from 0 (never) to 6 (always) with the response relating to how often the participant engaged in various activities “in the past three (3) days/nights”. The RESTQ-Sport is comprised of 75 items within 19 subscales covering general and sport related stress and recovery. The subscales were divided into six scores: general stress and recovery, sport-specific stress and recovery, and global stress and recovery which were a combination of the general scales and the sport-specific scales.

2.7. Treadmill Fitness Test

The treadmill test protocol started at 13.5 km/h and 1% grade with subsequent speed increments of 0.3 km/h each minute, until exhaustion. Heart rate was recorded at each 1-minute stage (Forerunner 405CX, Garmin, Kansas, USA). Expired gases were collected and analysed using a metabolic cart (Moxus, AEI Technologies, USA). Maximal VO_2 and the ventilatory threshold (VT) were defined as previously described [21].

2.8. Energy Expenditure Test

An incremental submaximal treadmill test was conducted to establish energy expenditure during exercise and daily ambulation. The test comprised of six, 4-minute stages; commencing at seated rest and continuing with 4, 6, 8, 10, 13 and 16 km/hr consecutively with 1% grade. Minute ventilation, expired gases and heart rate were recorded as for the treadmill fitness test. The relationship between heart rate and VO_2 was represented by the following equation (VO_2 (ml/min) = 30.986 * heart rate - 1136, r^2 = 0.9972). Energy expenditure (EE) was measured in kcal and calculated, as previously described [22]. This equation was applied to heart rate data collected every minute for 24-hours for three consecutive days. As it has been suggested that daily non-exercise energy expenditure (NEAT) is not compensated for by a more sedentary lifestyle while undertaking training [23], the EE calculated was used as an estimate of daily EE over the course of the study. Three days following the participant's return from overseas the submaximal test was repeated. The equation derived (VO_2 (ml/min) = 35.183* heart rate - 1598.6, r^2 = 0.9835) was applied to 24-hour heart rate data, collected while the participant was overseas, to determine an estimate of daily EE during these four weeks.

2.9. Quantification of Training

Training was quantified using the training times and heart rates to calculate time spent in pre-determined training intensity zones using a modified version of the training impulse (TRIMP) method [9,10].

2.10. Modelling

Performance at day *n (pn)* was calculated using consecutive training impulses recorded from the study; initiation through to performance day (W_i) with i varying from 1 to n-1, as shown in (Eq 1):

$$\hat{p}_n = p^* + k_1 \sum_{i=1}^{n-1} w_i e^{-(n-i)/\tau_1} - k_2 \sum_{i=1}^{n-1} w_i e^{-(n-i)/\tau_2} \qquad (1)$$

The following parameters defined the model performances: a positive (k_1) and negative (k_2) weighting factor expressed in arbitrary units (au), decay constants expressed in days: fitness (τ_1) and fatigue (τ_2), and an additive term (p*) that represented the initial performance level. A default value of 1000 was assigned to p*, and fatigue assumed to be zero. The actual performances were converted to a criterion point score out of 1000; with 1000 equalling the participant's personal best time in the preceding 12 months for 10000m. The model parameters were repetitively modified by minimising the residual sum of squares (RSS) between modelled and actual performances, initially starting with the default parameters τ_1 = 45, τ_2= 15, k_1 = 1, k_2 = 2, base 1000. The developers of this model indicate that the parameters may waver after 60-90 days of training or with changes to training protocol altering the goodness of fit [24]. Therefore, due to the duration of the study (122 days) the model was split at day 66 which coincided with a change in the participant's training, and the model parameters recalculated using the final fitness score from the first phase as the base and the same initial default parameters.

The following equation (Eq 2) was used to calculate the fatigue component (negative function, NF) and compared to weekly questionnaire and food diary responses.

$$NF_n = k_2 \sum_{i=1}^{n-1} w_i e^{-(n-i)/\tau_2} \qquad (2)$$

2.11. Statistical Analysis

Data were tested for normal distribution using a Kolmogorov-Smirnov test [25]. The meaningfulness of the model was assessed as previously described [9]. The coefficient of determination (r^2) provided the percent variation explained by the model and aided in determining the goodness of fit for the model. The fit was considered statistically significant if P<0.05; this was ascertained by an analysis of variance on the residuals with associated degrees of freedom. The Pearson Product-Moment Correlation Coefficient was used for analyses of the correlation between the modelled fatigue component and the scores of the POMS, RESTQ-Sport and average consumption of macronutrients as obtained from the food diaries. All statistical analysis was performed using PASW Statistics 18.

3. Results

The participant's aerobic fitness (VO_2 max) improved from 66.2 ml/kg/min to 70.9 ml/kg/min at day 75, with corresponding ventilatory thresholds occurring at 92 and 90%, respectively. Aerobic fitness decreased slightly (VO_2 max: 69.5 ml/kg/min; ventilatory threshold: 89%) following the participant's subsequent five weeks overseas. The weekly time-trial performances across the 18-week training period had average speeds ranging from 3.667 to 4.253 m/s; representing 10000m times between 39 mins 11 s and 45 min 27 s.

The model, while statistically significant, only explained 24% of the variance in the actual performance test times (Table 1). When the training period was split into two sections and remodelled, the ability of the model to explain large portions of the variance in performance improved (Model B: r^2 = 0.55, P = 0.02*;* Model C: r^2 = 0.87, P = 0.002; Table 1, Figure 1).

Table 1. Performance Fit and Model Parameters

Model	A	B	C
Training days	1-122	1-66	66-122
τ_1 (days)	30	30	60
τ_2 (days)	30	30	27.74
k_1	0.0025	0.0025	0.02
k_2	0.02	0.014	0.067
k_2/k_1	8.25	5.80	2.98
r^2	0.24	0.55	0.87
P	0.05	0.02	0.002

τ_1 = fitness, τ_2 = fatigue, k_1 = positive weighting factor, k_2 = negative weighting factor.

The nutritional analysis revealed an average intake, over the entire 18 weeks, of carbohydrate 2266±526 kCal/day, fat 733±363 kCal/day, protein 417±85 kCal/day, with total energy intake averaging 3416±840 kCal/day. When subtracting the average energy intake from the estimated energy expenditure the average energy balance was found to be -739±777 kCal/day for typical working lifestyle, -1854±503 kCal/day while the participant was overseas and -1087±869 kCal/day for the entire study as a whole. When comparing average dietary patterns with the psychological analysis of the POMS and RESTQ-Sport (Table 2), significant relationships were most commonly found between positive mood states and recovery activities.

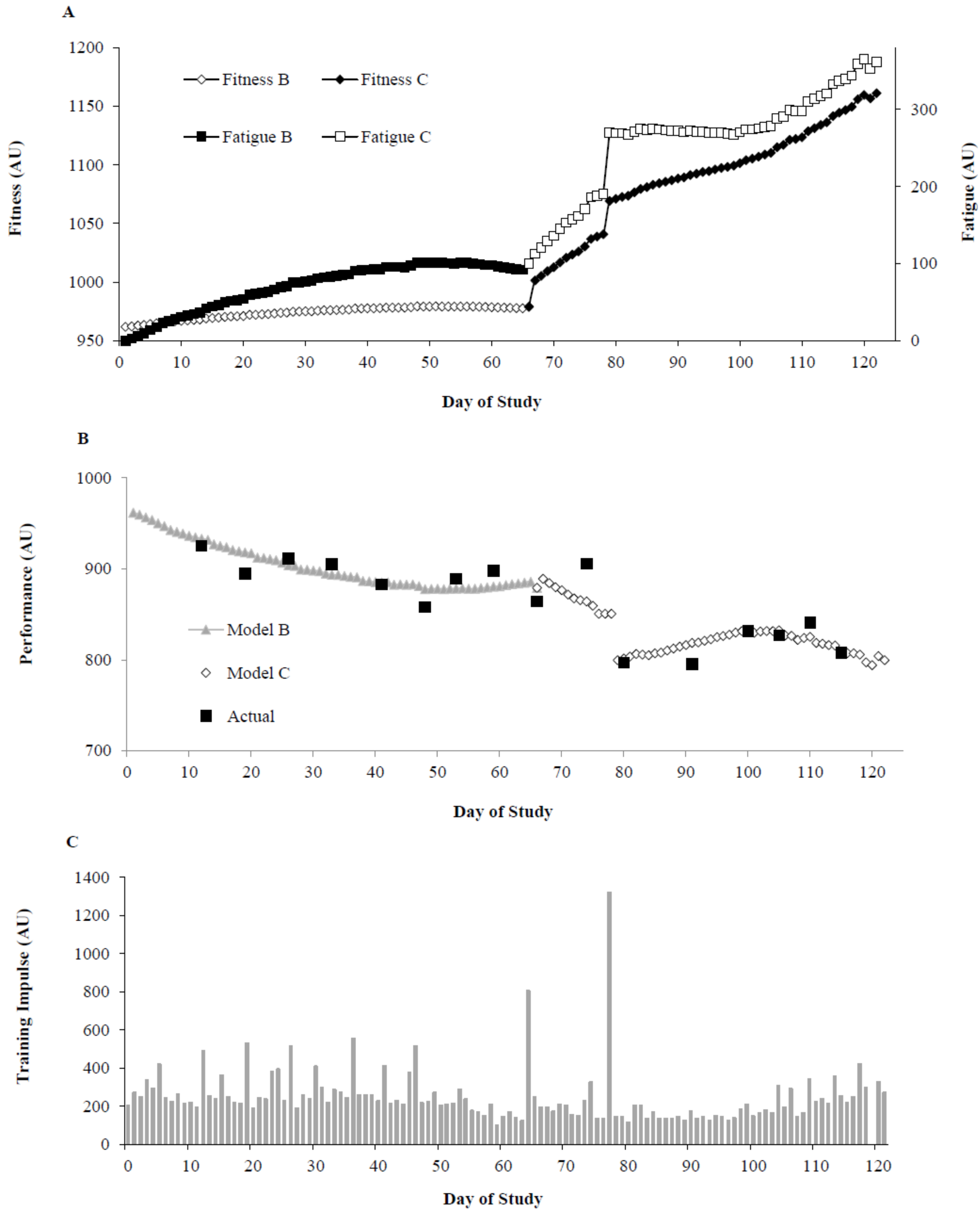

Figure 1. Model-predicted and Actual Performance, Fitness, Fatigue, and Training Impulse for Days 1 - 122: (A: Model-predicted (Models B and C) and actual performance, B: Modeled (Models B and C) fitness and fatigue, C: Training impulse. All values are in arbitrary units (AU))

Table 2. Correlation Matrix of Nutrition and Psychometric Factors for Days 1-122

	Nutrition				POMS							RESTQ-Sport					
	CHO	Fat	PRO	EI	TMD	TEN	DEP	ANG	VIG	Fatigue	CON	GS	GR	SS	SR	Glo S	Glo R
Glo R	0.383	0.628**	0.229	0.535*	-0.672**	-0.117	-0.224	0.579*	0.809**	-0.203	-0.508*	0.134	0.978**	-0.296	0.986**	-0.061	1
Glo S	0.217	0.139	-0.309	0.165	0.396	0.251	0.635**	0.240	0.188	0.676**	0.022	0.906**	0.031	0.837**	-0.132	1	
SR	0.358	0.607*	0.274	0.515	-0.651**	-0.126	-0.300	0.570*	0.786**	-0.215	-0.496	0.090	0.931**	-0.383	1		
SS	0.031	0.012	-0.287	-0.005	0.354	-0.064	0.676**	-0.133	-0.099	0.498*	0.135	0.527*	-0.175	1			
GR	0.400	0.631**	0.164	0.540*	-0.673**	-0.100	-0.120	0.567*	0.808**	-0.179	-0.504*	0.184	1				
GS	0.313	0.206	-0.257	0.259	0.341	0.439	0.464	0.475	0.368	0.666**	-0.071	1					
CON	-0.544*	-0.416	-0.312	-0.552*	0.622*	0.225	0.391	-0.303	-0.540*	0.110	1						
Fatigue	-0.192	-0.072	-0.374	-0.189	0.561*	0.228	0.288	0.018	-0.019	1							
VIG	0.609*	0.780**	0.195	0.739**	-0.633**	0.057	-0.215	0.375	1								
ANG	0.287	0.071	-0.004	0.210	-0.002	0.134	0.138	1									
DEP	-0.212	-0.261	-0.542*	-0.300	0.549*	0.192	1										
TEN	0.155	0.215	0.055	0.196	0.402	1											
TMD	-0.453	-0.584*	-0.360	-0.573*	1												
EI	0.927**	0.816**	0.658**	1													
PRO	0.624**	0.382	1														
Fat	0.550*	1															
CHO	1																

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Nutrition		**POMS**		**RESTQ-Sport**	
CHO	Carbohydrate	TMD	Total Mood Disturbance	GS	General Stress
PRO	Protein	TEN	Tension	GR	General Recovery
EI	Energy Intake	DEP	Depression	SS	Sport Stress
		ANG	Anger	SR	Sport Recovery
		VIG	Vigour	Glo S	Global Stress
		CON	Confusion	Glo R	Global Recovery.

Across the course of the study, the participant's subjective mood states Vigour and Fatigue, as determined by the POMS, had the greatest variability relative to the standardized T-Scores. Vigour declined steadily to reach 54% of baseline levels by the end of the study, while Fatigue declined to 61% of baseline and spiked above the average on days 69 and 83. All other mood states remained relatively stable over the 122 days. In comparison, all scores of the RESTQ-Sport declined over the course of the study, the greatest being the Sport-Specific Stress score which declined to 19% of baseline.

The strongest relationship between the POMS and the RESTQ-Sport (Table 2) was found between the Vigour (POMS) and all recovery subsets of the RESTQ-Sport (r = 0.80 - 0.81, $P < 0.01$). Moderate, but still significant, correlations were found between Total Mood Disturbance (POMS) and all recovery subsets (r = -0.65 - 0.67, $P < 0.01$); Depression (POMS) and Sports Stress and Global Stress (r = 0.64 and 0.68, $P < 0.01$); Anger (POMS) and all recovery subsets (r = 0.57 - 0.58, $P < 0.05$); Fatigue (POMS) and General and Global Stress (r = 0.6 - 0.68, $P < 0.01$) and Sport Stress (r = 0.50, $P < 0.05$); and Confusion (POMS) and General and Global Recovery (r = -0.50 - 0.51 $P < 0.05$).

As the second training phase (days 66-122) explained the largest portion of the variance between modelled and actual performance (87%), only this phase was considered in the evaluation of the fatigue component of the model. Correlations were determined between the dependent variable, modelled fatigue, and the independent variables, nutritional data and POMS, RESTQ-Sport (Table 3).

Table 3. Correlation of Modeled Fatigue and Independent Variables for Days 66 - 122

Nutrition		POMS		RESTQ-Sport	
CHO	-0.463	TMD	0.581	GS	-0.339
Fat	-0.884**	TEN	0.168	GR	-0.862**
PRO	-0.138	DEP	-0.336	SS	-0.826*
EI	-0.657	ANG	0.047	SR	-0.845**
		VIG	-0.959**	Glo S	-0.593
		Fatigue	-0.071	Glo R	-0.881**
		CON	0.374		

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

Nutrition		**POMS**		**RESTQ-Sport**	
CHO	Carbohydrate	TMD	Total Mood Disturbance	GS	General Stress
PRO	Protein	TEN	Tension	GR	General Recovery
EI	Energy Intake	DEP	Depression	SS	Sport Stress
		ANG	Anger	SR	Sport Recovery
		VIG	Vigour	GloS	Global Stress
		CON	Confusion	GloR	Global Recovery.

4. Discussion

This is the first study to utilise nutritional data and psychometric questionnaires (Profile of Mood States (POMS), Recovery-Stress Questionnaire for Athletes (RESTQ-Sport)) to investigate the fatigue component of a performance predicting model in enduran.

4.1. Model

The use of the Banister [1] model to predict performance in an endurance runner was successful when the training period was split into two separate phases. The performance fit was poor (Model A) when modeled for the total 122 day period, which could be attributed to the parameter's inability to accurately predict performance beyond 60-90 days [26]. However, the fit was significantly improved for the first (Model B) and second (Model C) training phases respectively (Table 1, Figure 1). The decision to divide the data from day 66 was based on the participant entering a new training phase [27,28], as previous reports have indicated that training phase changes alter the athlete's ability to retain fitness and/or reduce fatigue [26]. Other studies have also reported significant improvements in the fit of the model when applying a new set of parameters to different training phases [28,29].

A possible consideration for the moderate fit in Model B is that relative to training load, training intensity was not great enough to produce the desired performance improvements [1]. While the fit between modeled and actual performance seen in Model C (Table 1, Figure 1), is comparable to other studies using aerobic disciplines and similar training durations [2,5,9,10,28,29,30]. On day 78 the participant competed in a 96km event which was associated with an increase in fatigue and a smaller elevation in fitness, resulting in a dramatic drop in modeled performance, mirrored by a reduction in actual performance. As training impulses remained at their lowest for the 122-day period and in combination with an overseas trip, fatigue began to subside and performance improved (Days 66-105, Figure 1). However, despite the fitness component doubling (Model C, Table 1), performance times still remained the slowest of the 122-day period, and began to decline steadily again at day 105 when training impulses began to increase (Days 66-105, Figure 1). This is an interesting finding and could be attributed to performance improvements typically being more closely related to significant reductions in the negative influence of training (fatigue) rather than increases in the positive (fitness) [19]. These fatigue dominated performances could therefore be the result of consecutive days of intense training as was found in previous studies [19,27,28], where fatigue was possibly being retained through the absence of adequate recovery (i.e. non-training days).

4.2. Nutrition

Average energy intake was similar to studies reporting dietary analysis data for endurance athletes using the same type of survey [31,32,33]; however energy intake relative to energy expenditure was inadequate, especially during the second training phase. A large proportion of this deficit could be explained by the limitations of the measurement tools used, as food diaries are known to underestimate energy intake and 24-hour heart rate monitoring generally overestimates energy expenditure [34], in addition to the participant's weight remaining stable.

Table 2 shows the correlations between nutrition and questionnaires, and although casual relationships cannot be interpreted from these results certain inferences can be made. Increases in recovery activities, as determined by the RESTQ-Sport, related to significant increases in the consumption of fat and overall energy intake (Table 2). The Vigour subset of the POMS had stronger significant relationships with fat and energy intake as well as with carbohydrate (Table 2). This could be interpreted as the more time the participant spent engaging in recovery activities, the more opportunity there was to increase food intake, thereby contributing to increased levels of vigour.

4.3. Psychometric Factors

Previous reports using the POMS to assess the mood of athletes have found that active individuals usually score below the population average for Tension, Depression, Anger, Fatigue and Confusion scales, and one standard deviation above the population average for the Vigour scale, commonly referred to as the "Iceberg" profile [16,35]. On three occasions (days 29, 36 and 44) the participant's POMS profile sheet resembled this "Iceberg" profile, which in support of the literature, also followed the second, third, and seventh best performances of the study.

On all other occasions the profiles failed to resemble this "Iceberg" profile, yet neither did they represent overtraining, symbolized by an inverted "Iceberg" profile [16]. This is due to Tension, Depression, Anger, Fatigue and Confusion scores all oscillating between the population norm and one standard deviation below with a trend for Total Mood Disturbance to increase, although not exceeding norms [36]. In addition, the Vigour scale declined without a reciprocal increase in Fatigue scores, conflicting with the results of other studies using cyclists [37], swimmers [38] and ballet dancers [39], where progression through intensive training resulted in an inverse relationship between the two scores.

Overall the physiological performances of the participant indicated that overreaching or overtraining was present, yet the psychological responses to the training load were positive rather than negative. This disconnect between the expected physiological and psychological responses to training has also been previously reported [40], whereby an athlete was physiologically in good health yet considered overtrained by the POMS. The decline in Vigour as training progressed could also be indicative of the Vigour and Fatigue scales being more related to the physiological state rather than the psychological [37]. This notion works in favor of the current study attempting to give physiological meaning to a training model.

The second phase of training had a similar unpredicted effect on the participant's recovery-stress state (RESTQ-Sport);

where recovery activity was reduced and stress increased despite a reduction in total training volume. An improvement in performance was evident on days 100, 105, and 110 (Figure 1) possibly due to the reduced training stress; however, recovery activities were also reduced, contributing to the failure for performance to improve to at least baseline levels. Hence the relevance of this questionnaire is indicated, identifying that the absence of adequate recovery will prevent performance improvements despite reductions in stress. It is this incorporation of frequency of recovery activities into the psychological assessment that differentiates the RESTQ-Sport from the POMS [20] Alternatively, the participant may have perceived training itself as a recovery activity; as he was a non-professional athlete with a full time job and a family. This is supported by the significant relationships found between certain recovery scales of the RESTQ-Sport and the weekly training load (r^2 = 0.25 - 0.36, P = 0.005). Increases in the weekly TRIMPS resulted in the participant reporting improved feelings of general well-being, being in shape, and self-efficacy and a reduction in general and emotional stress.

The relationship between the two psychometric questionnaires (Table 2) was similar to what has been previously reported [20,41] with all recovery and stress scales of the RESTQ-Sport significantly correlating with the Vigour and Fatigue scales of the POMS respectively. The POMS Anger scale had weak yet significant positive correlations with all recovery scales of the RESTQ-Sport, which demonstrates the possibility of anger being a desirable quality of endurance athletes. A comparable finding was reported in a study attempting to predict race placement from mood states in a group of cross-country runners, where performance times improved as Anger (POMS) increased [35]. This and the data of previous studies [42] suggests that both questionnaires are sensitive to the dose-response relationship between training load and mood.

4.4. Modeled Fatigue Component

The second training phase (Model C, Table 1) was selected as the evaluation time period as it had the strongest and most significant relationship between actual and modeled performance. During this training phase the Vigour subset of the POMS accounted for 96% of the variance in modeled fatigue (Table 3); a vastly improved result when compared to the previous best fit where POMS Fatigue explained only 56% of the variance [10]. This study however found POMS Fatigue to be unrelated to modeled fatigue (Table 3). This lack of relationship indicates that the participant did not perceive the training as fatiguing as defined by the POMS; indicating, as previously reported that athletes may psychologically adapt to training loads [43,44]. Athletes have also been reported to have accentuated positive mood states [45,46], which could explain the subjective decline of Vigour rather than an increase in the negative mood state of Fatigue. Relating this idea to the model, it implies that training intensity was insufficient to produce a subjectively fatiguing response, and it was possibly training frequency that was interfering with recovery, therefore reducing the participant's perceived Vigour. This supports the finding of this study whereby through a lack of recovery, fatigue was being retained thus preventing performance improvements.

An interesting finding was the explanation of variance in modeled fatigue made by the macronutrient fat (Table 3). Fat was also significantly correlated to all the recovery scores of the RESTQ-Sport and Vigour (POMS) and negatively correlated to Total Mood Disturbance (Table 2). This suggests that in the energy deficient state elevated fat intake could assist in the recovery of endurance athletes, enhancing vigor, while reduced intake contributes to fatigue. Whether this relationship exists because fat has a greater energy density and therefore a greater impact on energy balance per gram of food consumed or purely because the participant selected foods with a high-fat content as part of a recovery routine cannot be determined. Nevertheless, this result indicates the utility for nutritional data to be another avenue for predicting modeled fatigue.

From the literature it was assumed that carbohydrate intake would influence the fatigued state as it has limited storage capacity within the body, facilitates fat oxidation during aerobic exercise, and is required from an exogenous source to replace muscle glycogen [47,48]. However, carbohydrate was not significantly correlated to modeled Fatigue but was significantly correlated with POMS Vigour (Table 2). This lack of significance could be indicating the fatiguing effect of commitments unrelated to energy expenditure like work and family stressors, which would not be relieved by the consumption of carbohydrate.

5. Conclusion

The results of this study indicate an excellent relationship between the fatigue parameter of the model, the participant's dietary fat intake, and scales of the psychometric questionnaires. Performance improvements appear dependant on the ratio of training load to appropriate recovery and decreased participation in recovery activities also appears to remove the opportunity for the athlete to meet nutritional requirements, further contributing to fatigue.

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