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Validity of Critical Velocity Concept for Weighted Sprinting Performance

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ABSTRACT

International Journal of Exercise Science 11(4): 900-909, 2018. We investigated the validity of a recently developed equation for predicting sprinting times of various tactical loads based upon the performance of a running 3-min all-out exercise test (3MT). Thirteen recreationally trained participants completed the running 3MT to determine critical velocity (CV) and finite running capacity for running velocities exceeding CV (D'). Two subsequent counterbalanced loaded sprints of 800 and 1000 m distances with 20 and 15% of their body mass, respectively, were evaluated. Estimated times (t, sec) for running 800 and 1000 m with a tactical load was derived using $t = (D - D')/CV$. Critical velocity adjusted for an added load using the following regression equation: original CV + (-0.0638 x %load) + 0.6982, D was 800 or 1000 m, and whole percentage load was ~15 or 20% of the participant's body mass. From the 3MT, CV (3.80 ± 0.5 $m \cdot s^{-1}$) and D' (200 ± 49.88 m) values were determined. The typical error of predicting actual times for the 800 and 1000 m loaded sprints were 5.6 and 10.1 s, with corresponding ICCs of 0.95 and 0.87, and coefficient of variations of 2.9 and 4.3%. The effect size differences between estimated and actual sprint times were small (0.27) and moderate (0.60) for 800 and 1000 m, respectively. The adjustment to CV through the regression equation yields small to moderate overestimates of maximally loaded sprint times for distances of 800 and 1000 m. Whether such errors remain pervasive for prescribing high-intensity interval training is unclear and requires further investigation.

KEY WORDS: 3-minute all-out exercise test, load carriage, high-intensity interval training

INTRODUCTION

Tactical professionals (e.g., military, law enforcement, fire, and rescue) often face load carriage as a fundamental problem in these environments (i.e., battlefields, structure fires, etc.). Load carriage is the external load carried as part of the demands of the occupation, which takes the form of duty belts, equipment, weapons, body armor, and different types of protective gear (4, 11, 16, 22). Load carriage limits the mobility and efficiency of tactical professionals through increased energy cost and perceptual effort to complete functional tasks (3, 14, 17, 22, 24). Prominent performance decrements (i.e., increased times for completion of tasks) as a result from load carriage, have produced numerous specialized conditioning programs that have been implemented to compensate for the loads used (6, 7, 12, 18, 25). As part of concurrent training, high-intensity interval training (HIIT) has contributed to improvements in load carriage performance as well as occupationally specific tasks (7).

The running 3-min all-out exercise test (3MT) over ground, provides estimates of critical velocity (CV) and running capacities at speeds exceeding CV (*D′*)(19). The CV represents the speed that can be maintained for an extended period by the aerobic energy systems. Conversely, when individuals run at velocities exceeding CV, the finite capacity of *D′* regulates the time delay of the slow component in the rise toward maximum oxygen uptake (VO_{2max}) (21). The higher the *D′*, the longer distance the runner can travel at speeds exceeding CV, where running performance is found to be dependent on both CV and *D′* (19). Critical velocity has been associated with technical and combat-specific performance measures in tactical populations. As the CV concept evaluates both aerobic and anaerobic training needs, it has been examined as an alternative to the Unites States Army Physical Fitness Test, that only assess aerobic fitness with a 3.2 km run (5). Critical velocity has been associated with performance in repeated 30 m sprinting shooting and running over a distance of 2.5 km (8). More recently, using the CV concept has shown the plausibility of use prescribing interval training for training tactical professionals with load carriage (23). Solomonson et al. (2016) developed a regression equation to identify the relationship between the load carriage percent of body mass (BM) (15-25%) and decreases in CV (23). After completing an unloaded running 3MT, the regression equation could be used to prescribe HIIT with an assigned amount of load carriage (15- 25% body mass).

The CV concept has been used as a method of interval exercise prescription with collegiate level soccer players and demonstrated the improvement in aerobic capacity (6%) from a two day per week 4-week training program (2). The advantage of using this model is prescribing intervals based on a percentage of *D′*, and CV relative to participants' anaerobic and aerobic measures, respectively (10). Thus, a model of HIIT prescribed using the CV concept that adjusts CV correctly for load would be of considerable importance for improving tactical performance. By decreasing the effects load carriage has on running economy and velocity, it could conceivably enhance the survivability of tactical professionals (15). The primary purpose of this study was to investigate the influence of external load on short/middle distance sprinting performance based on the performance of a running 3MT. The secondary purpose was to validate estimated decreases in CV calculated from an unloaded 3MT to two separate loaded sprints of 800 and 1000 m with 20 and 15% of the participant's body mass.

METHODS

Participants

A sample of 13 recreational trained participants (10 males and 3 females) from military occupational backgrounds (mean ± SD, age = 21 ± 4 yrs, height = 175 ± 9 cm, mass = 77 ± 10 kg, body fat % = 13.8 ± 5.9) completed this study. Height was assessed using a portable stadiometer (Seco Corp, Model 213, Hamburg, Germany); weight and body fat percent were assessed on a body composition analyzer digital scale (Tanita, Model TBF-300A, Arlington Heights, IL, USA). The participants were defined as recreationally active by completing both aerobic and resistance training 2-5 days per week for at least the past six months. Additionally, the participants were familiar or had experience with load carriage either through duty gear, body armor or backpack wear. During the first visit, all participants read and signed the informed consent document. All procedures for this study were approved in advance by the host university's Institutional Review Board.

Protocol

This study was an experimental design to investigate the relationship between external loading (percentage of body mass) and decreases in CV or aerobic capacity. The hypothesis was that by using a previously established linear regression model (23), researchers could accurately predict run times for different distances under load. A group of recreationally trained participants completed an unloaded 3MT and then ran two different loaded sprints at 800 m and 1000 m with ~20 and 15 % of participants' body mass, respectively, in a randomized order. Prior to each trial, 5 minutes of warm-up was provided which consisted of light jogging and dynamic movements.

On the first testing day, the participants performed the 3MT. This test took place on an outdoor 400-m running track with moderate temperatures and minimal wind conditions. Participants were instructed to accelerate to maximal speed and to try to maintain maximum speed for the duration of the test. Participants were not given the elapsed time nor the remaining time to discourage pacing. Verbal encouragement was provided. Researchers placed cones around the inside of the track at 20-m intervals. Simple manual timing was used by calculating the displacement of the participant over the 20-m intervals. As a participant ran past each cone, an investigator recorded split time using a commercial stopwatch (495; Ultrak, Gardena, CA, USA). Split times were entered into a spreadsheet (Microsoft Office 2016, Excel) and velocities were calculated using the change in displacement relative to the change in time. Critical velocity was calculated as the mean speed during the last 30 seconds of the 3MT. Anaerobic capacity (*D'*) is calculated from the average velocity during the first 150 seconds (V_{150s}) with the following equation (19):

$$D' = 150s\,(V_{150s} - CV). \quad [a]$$

To ensure the participant was not pacing the test, investigators calculated the slope of the last 30 s of the test. Whereby a slope of 0.0 would be indicative of the absence of pacing. Figure 1 provides a sample of a representative participant completing the 3MT.

The loaded sprints (visits 2 and 3) involved running specified distances of 800 m and 1000 m with an external weight of 20 and 15% of participants' body mass respectively. Sprints were randomized for each participant and occurred on separate days with a minimum of 48 hours between the two trials. Load carriage was completed by the participant wearing an adjustable, weighted, short-waist vest (VMax Weightvest.com, Rexburg, ID, USA). The participant was fitted and adjusted for comfort before testing. The external load selection was made as a percentage of the participant's body mass (i.e., participant weighing 70 kg for 20% of body mass would carry a load of ~14 kg). The vest's mass increments were 1.1 kg; thus, investigators selected the closest increase to the desired mass that was feasible. The sprints were run on the same track as the 3MT with similar weather conditions and timed via stopwatch. Researchers used data from the 3MT to estimate time to complete the sprints (SPRt) through the following equation:

SPRt = (D – *D'*)/CV. [b]

Where SPRt is the estimated sprint time (s), D is the distance of the sprint and *D'* from equation a. The adjusted load carriage CV was calculated through the following (23):

Adjusted CV = Original CV + (-0.0638 x % load) + 0.6982. [c]

Investigators use the completion times to validate the effects of additional weight on sprinting performance.

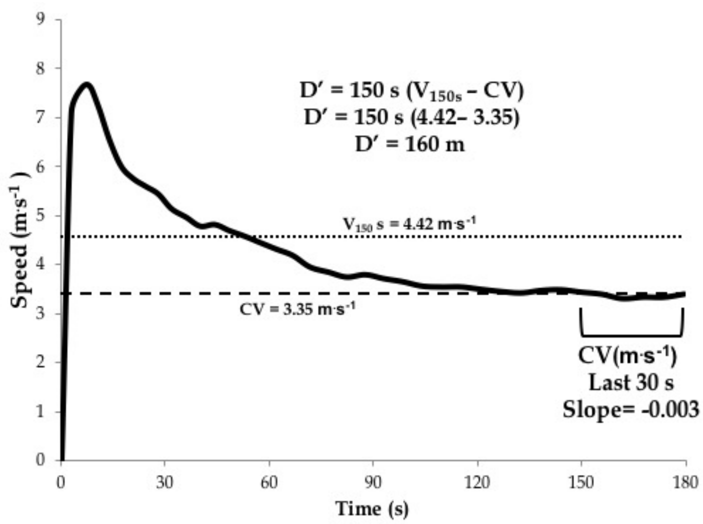

Figure 1. Representative 3- minute all-out exercise test.
CV= Critical Velocity; D′= Anaerobic capacity; V_{150s} = the average velocity during the first 150 seconds

Statistical Analysis
Actual and predicted times for the two distances were evaluated with a series of paired t-tests. Measurement agreement will be assessed using interclass correlation coefficient (ICC), typical error, and coefficient of variation. Bland-Altman plots were used to determine differences across ranges of performances (1). A one-sample t-test was used to compare the fitness levels of the present sample with the study that derived equation c. Pearson r correlation was used with CV slope measures and difference in the estimated versus actual sprint times (9). Descriptive statistics are reported as mean ± SD. Effect size (ES) differences from predicted to actual times using Cohen's d (mean difference divided by pooled SD). Statistical significance was defined by a significance values of $p < 0.05$. All calculations were performed using statistical software (v.24.0; Statistical Package for Social Science software, Chicago, IL, USA).

RESULTS

From the 3MT, CV (3.80 ± 0.5 m·s^{-1}) and *D′* (200 ± 49.88 m) values were determined (Table 1). There were no significant differences in CV ($t = 0.58$, $p = 0.576$) and *D′* ($t = 0.40$, $p = 0.695$) from the originating of Solomon et al. (2016) who reported CV and *D′* values of 3.72 ± 0.38 m·s^{-1} and 201.8 ± 51.54 m, respectively. The slope of the last 30 s of the 3MT yielded values (-0.004 ± 0.007). Between the slope of CV and the estimated versus actual sprint times differences, a very large correlation with statistical significance in the 800 m sprint ($r = 0.788$, $p = 0.001$) and small correlation with a lack of statistical significance in the 1000 m sprint ($r = 0.298$, $p = 0.322$) was observed. The typical error of predicting actual time for the 800 and 1000 m loaded sprints was 5.6 and 10.1 s, with corresponding ICCs of 0.95 and 0.87, and coefficient of variations of 2.9 and 4.3%. The regression model (188.7 ± 25.4 s) underestimated actual (195.2 ± 22.4 s) sprint times for the 800 m distance with ~20% load carriage ($t = 2.96$, $p < 0.01$). Similarly, estimated (229.5 ± 27.1 s) underestimated actual (244.9 ± 24.2 s) sprint times for the 1000 m distance with ~15% load carriage ($t = 3.95$, $p < 0.01$). The effect size differences between the regression model and actual sprint times were small (0.27) and moderate (0.60) for 800 m and 1000 m, respectively.

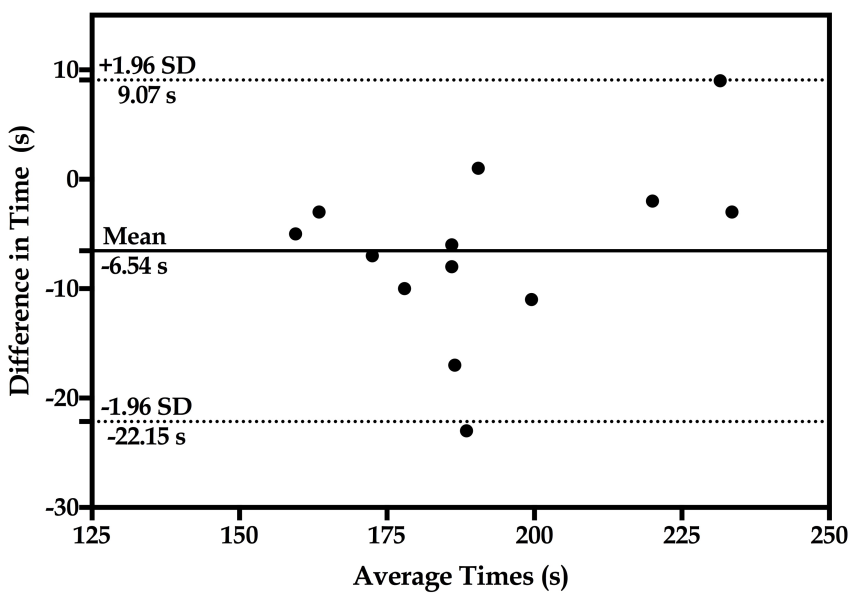

Figure 2. Bland Altman analysis of agreement between the differences in time from the estimated (regression equation) and the actual weighted sprinting performance for the 800 m. The middle solid line represents the mean differences ($p < 0.01$). The upper and lower dotted lines represent the bias ± 1.96 SD (95% Limits of Agreement).

Table 1. 3-min all-out running test and predicted versus actual times for the 800 m and 1000 m loaded sprints

Participants	CV ($m \cdot s^{-1}$)	*D′* (m)	800m Load (kg)	Predicted 800m (s)	Actual 800m (s)	1000m Load (kg)	Predicted 1000m (s)	Actual 1000m (s)
1	4.33	209	16.7	157	162	12.3	195	206
2	3.35	160	18.9	232	235	14.5	273	280
3	3.26	171	13.4	236	227	9.8	278	275
4	3.75	248	15.6	173	183	12.3	217	241
5	3.70	227	15.6	183	189	11.2	226	247
6	3.92	139	10.1	194	205	7.9	236	245
7	3.75	238	17.8	178	195	13.4	219	253
8	3.97	193	14.5	177	200	11.2	219	234
9	3.85	183	15.6	191	190	11.2	229	261
10	2.89	283	13.4	219	221	9.8	274	264
11	4.76	118	16.7	162	165	13.4	197	216
12	4.35	167	15.6	169	176	11.2	205	211
13	3.57	264	16.7	182	190	12.3	224	261
Mean	**3.80**	**200**	**15.4**	**189**	**195***	**11.6**	**230**	**246***
SD	**0.50**	**50**	**2.2**	**25**	**22**	**1.7**	**28**	**24**

*Significantly greater ($p < 0.01$) than the Predicted Times.

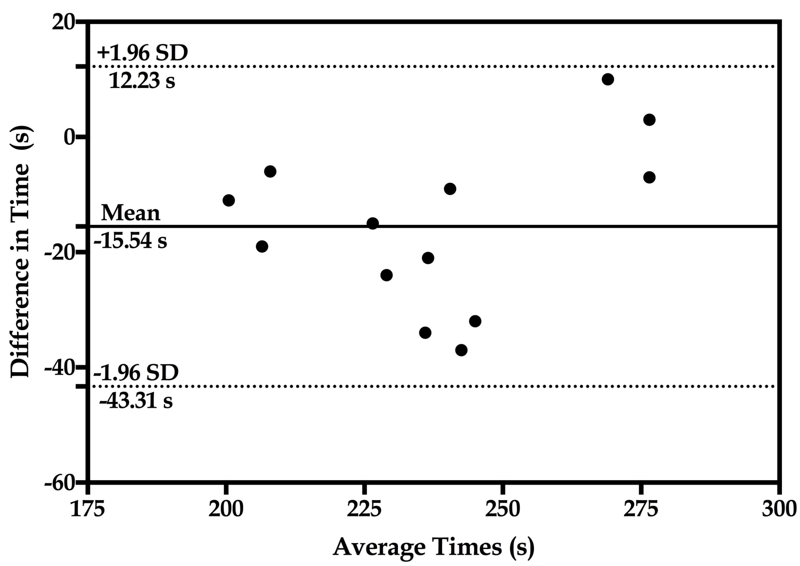

Figure 3. Bland Altman analysis of agreement between the differences in time from the estimated (regression equation) and the actual weighted sprinting performance for the 1000 m. The middle solid line represents the mean differences ($p < 0.01$). The upper and lower dotted lines represent the bias ± 1.96 SD (95% Limits of Agreement).

DISCUSSION

The primary purpose of this study was to examine the influence of external load on short/middle distance sprinting performance. The secondary purpose was to validate estimated decreases in CV calculated from an unloaded 3MT to two separate loaded sprints of 800 and 1000 m with 20 and 15% of the participant's body mass. The accuracy of the regression completing the 800 m sprint with ~20% of body mass was demonstrated by ICC = 0.95 and coefficient of variation = 2.9%, where slightly larger error observed for the 1000 m sprint with ~15% of body mass (ICC = 0.87 and coefficient of variation= 4.3%). The coefficient of variation percentages in the present study were similar to estimations of actual run performances of cross country runners completing 800 m , 1600 m and 5000 m distances (5.4%, 1.7% and 2.1%, respectively) (19). Due to the bioenergetic demands of the environment faced by tactical professionals, training to improve performance continues to be of critical importance.

Measures of CV and *D′* values determined with this sample were not significantly different from the values reported by Solomonson et al. (23). The aim with the present study was to validate a regression equation for tactical performance on a sample with similar fitness levels. Before these investigations, there has been little normative data published on CV and *D′* values in the tactical professional populations. In a sample of eighteen male soldiers from an Israeli elite combat special forces unit, higher CV values (4.09 ± 0.41 $m \cdot s^{-1}$) but lower *D′* values (78.56 ± 21.94 m) were reported (8). The *D′* values from the male soldiers were similar to those reported by female cross country runners (85.8 ± 40.5 m) (19). Conversely, recreationally active college aged young adults had similar *D′* values as our sample (204.2 m) and lower CV values (3.11 $m \cdot s^{-1}$) (5).

Athletes that have a requirement of more anaerobic energy systems tend to have higher D′ values up to 300 m (2, 13). Indeed, *D′* has shown to have some variability (2, 19, 23). The variability of *D′* can exceed 10% from day to day (20). During exercise in the severe domain (above CV), accelerated depletion of phosphocreatine and glycogen stores occur. Nutrition and supplementation modifications may affect *D′* (21). Intensities above CV, correspond with the rapid accumulation of fatigue-related metabolites (i.e., inorganic phosphates, adenosine diphosphate, H+) that impairs muscle contractile function. Though not fully understood, variability in *D′* exists and could explain the ~5 % coefficient of the variation in our estimations.

The running 3MT continues to show its utility to measure of both CV and *D′* with large groups of participants. With limited logistical and minimal time requirements, the 3MT is an ideal method for evaluating and prescribing exercise for tactical professionals. Tactical professionals are often called upon to carry out continued operations requiring optimal aerobic conditioning. Additionally, tactical professionals are often expected to face anaerobic challenges such as load carriage, sprinting, casualty evacuation, subject apprehension, etc. Thus, the results from the 3MT could be used to assess for technical readiness and used as standards for performance.

In the present study, the slope of velocity relative to time during the last 30 s of the 3MT (-0.004 ± 0.007). The need to establish a threshold at which a limit of the slope that is allowed for an accurate measure is warranted. Consequently, in a correlation of CV slopes and the differences between estimate vs. actual (s) sprinting performances there was a very large correlation (r = 0.788, p = 0.001) with the 800 m sprint. Mostly negative slope in the velocities was observed; there was a positive slope (0.012) that would be indicative of acceleration during the last 30 s, causing an inflated prediction of CV from the 3MT. With the 1000m sprint the correlation became small (r = 0.298, p = 0.322), this reduction could be due to the slight overestimation of CV causing an exponential error at increased distances. When an individual's CV becomes inflated consequently, there would be an overestimation of their sprinting performance. Thus, the need to accurately predict CV from the 3MT is imperative. From this sample, it is recommended the following values are used for upper and lower thresholds (0.006, -0.017) for CV slopes during the 3MT with 95% confidence interval. With a slope outside of this recommend confidence interval, the practitioner should retest the tactical professional.

High-intensity intervals prescription has been used to improve CV. Clark et al. (2013) were able to enhance CV in both groups of collegiate soccer players but at the cost of D′ (2). These investigators examined both short (600-800 m) and long (800-1000 m) intervals at 60, 70 and 80 % depletion of *D′*. A 6% increase in CV with a 13% decrease in *D′* was observed after a 4-week HIIT program. The use of the unloaded 3MT in combination with the adjusted CV regression equation would allow a similar HIIT prescription with load carriage. Based on the anaerobic demands of load carriage, training with load could increase the anaerobic capacity. As was recommended by Clark et al., load carriage HIIT would increase intensity due to the total work completed. Additionally, shorter intervals would yield increases in CV without negative effects of *D′*.

In conclusion, when using shorter intervals (<800 m or <180 s) for HIIT, the small overestimation with the regression equation would be moot. When using the equation, a typical error of < 6 s was seen with the 800 m sprinting performance. However, with longer intervals the error is increased (> 10.1 s). To decrease this error, further research should continue to investigate the effects load carriage has on CV. Furthermore, future research should investigate loaded HIIT prescription and its utility to improve load carriage performance. Such information will provide tactical strength and conditioning practitioners with an accurate method to prescribe load carriage exercise to increase fitness in the tactical professional population.

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