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ORIGINAL ARTICLE

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Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability

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Abstract The reliability and validity of a soccer-specific field test of repeated sprint ability was assessed. Seven male games players performed the repeated sprint test on six separate occasions. The temporal pattern of the mean sprint time was analysed by using coefficient of variation with confidence intervals (CI), and repeated measures ANOVA. A within subject mean coefficient of variation of 1.8% (95% CI, 1.5–2.4) was found for performance in the repeated sprint test across all six trials. The mean coefficient of variation across trials 2–4 was found to be 1.9% (95% CI, 1.3–3.1), compared to trials 4–6, where it was 1.4% (95% CI, 1.0–2.3). The ANOVA showed that a significant difference was present between the trials ($F_{6,30}$ 9.8, $P < 0.001$). A Tukey post-hoc test showed that significant differences were present between trial 1 and trials 3–6, and trial 2 and trial 5. The learning effect was complete by trial 3. Performance in the repeated sprint test was compared to total running time averaged from two repeats of the maximal anaerobic running test laboratory protocol. Mean sprint time in the repeated sprint test and total running time in the laboratory protocol had a correlation coefficient of $r = -0.298$ ($P = 0.516$, $n = 7$), suggesting that the energetics of the two tests are not closely related. In conclusion, this soccer-specific field test demonstrated high reliability.

Key words Football · Fatigue index · Criterion validity · Match analysis · Maximal intensity intermittent exercise

Introduction

The ability to produce high rates of power output and to sprint at high velocity is essential to performance in team invasion games, such as soccer. Sprinting has been shown to represent less than 10% of the distance covered in a match (Reilly and Thomas 1976; Withers et al. 1982; Ekblom 1986; Bangsbo et al. 1991), and yet it is considered critical to the outcome of a game. Furthermore, sprinting in soccer fluctuates in its intensity in a stochastic manner, so that a player may be required to sprint repeatedly, in any direction.

The term "repeated sprint ability" (RSA) was first introduced by Fitzsimons et al. (1993) and refers to the "ability to regularly reproduce maximal sprint efforts" (Dawson et al. 1993). In trying to understand the physiological mechanisms involved in RSA, various field tests have been developed (Tumilty et al. 1988; Dawson et al. 1991; Baker et al. 1993; Fitzsimons et al. 1993; Bangsbo 1994; Wadley and Le Rossignol 1998). These protocols have all taken similar formats, the sprint durations for each test varying between 20–40 m, the number of repetitions being 6–18, with recoveries of between 15–25 s. Each sprint time has been measured, with a mean sprint time being calculated and the decrement being used as a fatigue index. However, the validity of these RSA protocols has been poorly considered.

All previous studies involving RSA protocols have made some attempt to establish the logical validity of the protocol. Fitzsimons et al. (1993) and Wadley and Le Rossignol (1998) have claimed that a test of RSA will challenge the energy systems in a manner that closely replicates the game situation. However, only one of the protocols examined has used an active recovery (Bangsbo 1994). Most RSA protocols have involved unidirectional running and have neglected the multidirectional nature of a sport like soccer. Only the protocols of Baker et al. (1993) and Bangsbo (1994) have incorporated a multidirectional component.

Criterion validity has been examined by considering the correlation between maximal sprint tests and the Wingate test (e.g. Baker et al. 1993). Given the differences in the metabolism between continuous, short duration exercise (Kavanagh and Jacobs 1988) and intermittent, high intensity exercise (Gaitanos et al.

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1993; Balsom et al. 1994), the Wingate protocol might seem to be an inappropriate protocol against which to establish criterion validity. The Maximal Anaerobic Running Test (MART) of Rusko et al. (1993) offers an alternative basis for assessing criterion validity.

The assessment of reliability or learning has been shown to be poorly judged by simple test-retest correlation (Bland and Altman 1986). Through using a multiple trials design, to analyse reliability, the point can be calculated at which the learning effect ceases.

Only the test proposed by Bangsbo (1994) have incorporated an active recovery and multidirectional component, and yet no information exists as to its validity and reliability. Therefore, the purpose of this study was to evaluate the reliability and validity of the Bangsbo Sprint Test (BST), through adopting a multiple trials design and comparing it to a laboratory repeated sprint test.

Methods

Subjects

Seven male games players, whose mean age, height, mass and sum of the skinfolds (Durnin and Womersly 1974), were 23 (SD 4) years, 180.0 (SD 5.9) cm, 71.4 (SD 2.8) kg, and 43.6 (SD 7.3) mm, respectively, volunteered to take part. The subjects were national-level student players who averaged four training sessions and one match a week. The purpose, details and risks of the test procedures were explained to them, both verbally and in writing. This study was approved by the University of Brighton Ethics Committee. The experiments complied with the current laws of the United Kingdom.

Procedures

The validity of the BST was evaluated by comparison with the mean of two MART (Rusko et al. 1993). To examine the reliability of the BST, six BST trials were conducted. Prior to both the MART and the BST a single test was used to familiarise the subjects with each protocol. Tests were conducted over a 4-week period in random order.

Pre-test procedures

The subjects were asked to follow the recommendations given in a food guide (U.S. Department of Agriculture and U.S. Department of Health and Human Services 1992), to provide a structured consistent approach to daily nutritional intake over the test period.

On the morning of a test the subjects consumed two small snacks approximately 5 h preceding exercise and a further two snacks were consumed approximately 2–3 h before exercise. Each snack was designed to contain 55%–65% carbohydrate, and have an energy content of 150–200 kcal (American Dietetic Association 1987). Subjects were further instructed to consume 1 l of water 2 h prior to a main test to ensure euhydration. Verbal confirmation of compliance with these instructions was given by subjects prior to the tests.

The subjects refrained from drinking alcohol and caffeine containing fluids and heavy exercise during the 24 h before a test. Each test for each subject was completed within a similar 3 h period (e.g. subject A was always tested between 12.00–15.00 hours), to avoid the circadian variability that has been shown to occur in anaerobic performance (Hill et al. 1992). Subjects performing the MART wore shorts and training shoes whereas subjects performing the Bangsbo sprint test wore shorts and studded boots. Tests in the laboratory were conducted at a mean ambient temperature of 21.4 (SD 0.3) °C.

Main test procedures

Maximal anaerobic running test

All MART protocols were carried out using a motorised treadmill (Powerjog EG30, Sport Engineering Ltd., Birmingham, England). Subjects completed a 20 min warm up of jogging, sprinting and stretching, followed by 5 min rest. The MART involved repeated 20 s runs, each at increasing intensity, on a 10.5% gradient, with a passive recovery of 100 s between bouts as has been described by Maxwell and Nimmo (1996). Subjects started the test at a speed of 14.3 km $\cdot$ h^{-1}, with each subsequent run 1.3 km $\cdot$ h^{-1} faster than the previous one. Verbal encouragement was given. The protocol was terminated when the subject was unable to keep pace with the treadmill and was forced to jump astride the moving belt. Exhaustion time was taken as the time at which the hands were placed on the handrail. Running performance was expressed as total running time in seconds. Heart rate of the subject was measured immediately prior to each run and after 80 s of recovery using short-distance telemetry (Sport Tester, PE-4000, Polar Electro Fitness Technology, Bodycare Products Ltd., Kenilworth, England). Ratings of perceived exertion was assessed using the Borg 15 point scale at the end of each run (Borg 1982).

Bangsbo sprint test

This study used a modified version of the protocol first introduced by Bangsbo (1994), entitled the "sprint test", which was performed outside on a grass surface. The modification involved adding a random right or left turn component to improve the applicability to the vari-directional nature of team-sports and to place a demand upon both legs. The course thus possessed two possible directional diversions (Fig. 1). The protocol consisted of

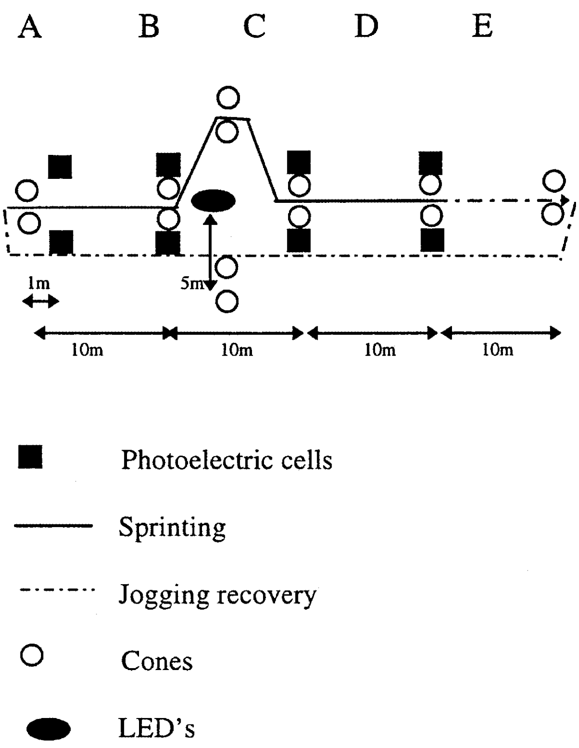

Fig. 1 Diagram of modified Bangsbo sprint test. For explanation of *A*, *B*, *C*, *D*, *E* see Methods section, Bangsbo Sprint Test. *LED* Light emitting diodes

seven maximal sprints along the portions A–D (Fig. 1) of the course, a distance of 34.2 m. Each sprint was followed by 25 s of active recovery, during which time the subject jogged the D–A (Fig. 1) part of the course, via E (Fig. 1), a distance of 40 m. This recovery run was timed so that the subject had returned to point A by between 23 and 24 s. The subjects began sprinting as soon as they saw the illumination of one of two light-emitting diodes (LED). The two LED (DLC2–6ID, RS Components, Corby, England) were located 10 m away from point A, were suspended 1 m above the ground and were 30 cm apart. The left positioned LED indicated that the subject should sprint the left diversion of the course, and the right positioned LED signified that the right diversion should be taken. Each sprint (total number over six trials = 42) was randomly assigned a direction, so that the experimenter knew which light to activate. Photo-electric cells (S2–1A5, RS Components) were placed along the sprinting portion of the course (Fig. 1). The timing system recorded the time taken between the illumination of the LED and the breaking of the light beam at each gate. Immediately upon passing point D, the timing of the subject's recovery run began. Verbal feedback was given at 5, 10, 15 and 20 s of the recovery. Performance was measured as the mean sprint time in seconds, and the mean of the time taken over the first two sprints was subtracted from the mean of the time for the last two sprints, to give a fatigue index.

The subjects completed a 15 min warm up (although same total running time as MART warm up) of jogging, sprinting and stretching, followed by 5 min rest.

Ambient temperature and relative humidity (rh) were taken before and after each test was performed using a digital thermometer and hygrometer (Testo 610, Testo Ltd, Alton, England), sensitive to changes of 0.1 °C and 0.1% rh, respectively. Wind speed was recorded parallel and at right angles to the straight component of the course, before and after each test. The wind speeds were ascertained using an anemometer (LCA 6000, Airflow, High Wycombe, England), sensitive to changes in wind speed of $0.01\ m \cdot s^{-1}$.

Statistical analyses

Data were tested for the violations of the assumptions of normality and where appropriate sphericity. Neither assumption was violated. Statistical significance was accepted at a P value of 0.05. Exact P values were reported, unless the value was $P < 0.001$. The data for mean sprint time was analysed using a repeated measures ANOVA, with a Tukey post-hoc test where appropriate. Mean coefficient of variation (CV) was calculated using a two-way analysis of variance on the log-transformed variable (Hopkins et al. 1999). The CV was then calculated using the following equation that has been reported by (Schabort et al. 1998):

$$CV = 100(e^{SD} - 1) \quad (1)$$

Confidence intervals (CI) for the CV were calculated using the method that has been described by Hopkins et al. (1999).

Results

Table 1 shows the within subject CV from test to test for mean sprint time in the BST, to be 1.8% (95% CI 1.5–2.4). Figure 2 shows the individual subject plots for mean sprint time throughout the six trials. A significant difference was found among mean sprint times ($F_{6,30} = 9.8$, $P < 0.001$). A Tukey post-hoc analysis subsequently established differences between the mean for trial 1 and trials 3, 4, 5 and 6, as well as between the mean for trial 2 and trial 5 (Table 1). A significant difference at the $P < 0.05$ level was calculated by the Tukey method, to equate to a difference in means greater than 0.214 s.

The mean time over the first 10 m of the course and mean time for the entire sprint section gave a correlation of $r = 0.805$ ($P < 0.001$, $n = 42$). The mean time between points B and C on the course (Fig. 1) and the mean time for the entire sprint section produced a correlation of $r = 0.703$ ($P < 0.001$, $n = 42$). Mean time for the last 10 m of the course and mean time for the entire sprint section gave a correlation of $r = 0.347$ ($P = 0.024$, $n = 42$). No significant difference was found among sprints along the left and right diversion of the course ($t_{292} = 0.463$, $P = 0.644$).

The average wind speed for the BST parallel to the course was $+3.34$ (SD 1.51) $m \cdot s^{-1}$. The average temperature and relative humidity during the BST tests was 13.0 (SD 4.0) °C and 58 (SD 14)%, respectively. Tests in the laboratory were conducted at a mean temperature of 21.4 (SD 0.3) °C and rh of 45 (SD 6)%.

Table 2 shows whether subjects fatigued between the first sprints and the last sprints of the test. For the whole course subjects slowed by an average of 0.184 s between the first two and the last two sprints. Significant slowing was demonstrated over each one-third of the course.

Mean total running time within the MART for all tests was 174 (SD 8.5) s. The within subject variation as expressed by CV for total time over the two trials was 2.1% (95% CI 1.4–4.7). The mean total times for trials 1 and 2 were 171.9 (SD 8.2) and 176.0 (SD 8.9) s, respectively.

Mean total time over the two trials of the MART, and the average for mean sprint time over all six trials of

Table 1 Within and between subject variances for mean sprint time (in seconds) across six trials of the Bangsbo Sprint Test. *CV* Coefficient of variation

Subject	1	2	3	4	5	6	7	Mean	SD
Trial									
1	7.755	7.851	8.048	8.401	7.724	7.672	8.207	7.951	0.275
2	7.473	7.577	7.946	7.906	7.675	7.456	7.918	7.707	0.215
3	7.409	7.364	7.731	7.892	7.394	7.713	7.860	7.623*	0.229
4	7.182	7.485	7.554	8.028	7.690	7.589	8.012	7.650*	0.300
5	7.263	7.223	7.361	7.685	7.576	7.364	7.747	7.460*,**	0.208
6	7.233	7.199	7.599	7.950	7.867	7.360	7.944	7.593*	0.333
Mean	7.386	7.450	7.707	7.977	7.654	7.526	7.948	7.664	
SD	0.212	0.245	0.256	0.237	0.159	0.154	0.155		
CV	2.8	3.3	3.3	3.0	2.1	2.0	2.0	1.8	

* Significant difference from the mean of trial 1
** Significant difference from the mean of trial 2

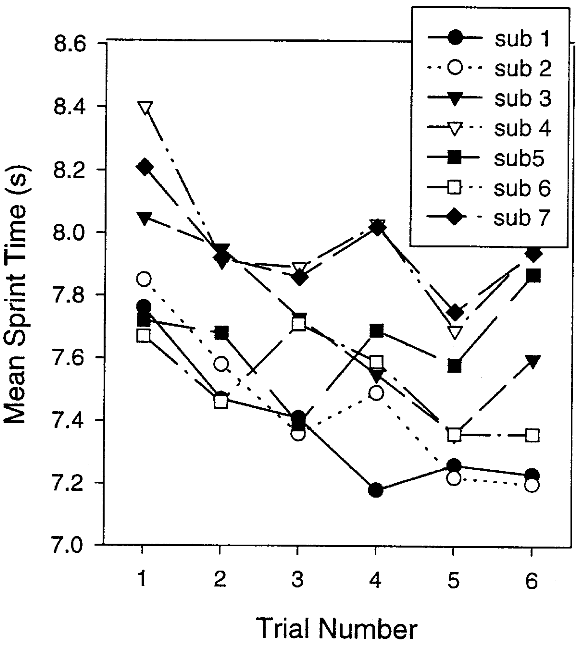

Fig. 2 Individual subject plots for mean sprint time for six trials of Bangsbo Sprint Test. *sub* Subject

the BST, had a correlation coefficient of $r = -0.298$ ($P = 0.516$, $n = 7$).

Discussion

The BST was found to have an average CV over the six trials of 1.82% (95% CI 1.45–2.43). Repeated measures ANOVA and subsequent post-hoc analysis revealed significant differences between trial 1 and trials 3, 4, 5 and 6, as well as between trial 2 and trial 5. Since no significant differences occurred after trial 2, this suggests that the BST is more reliable following a familiarisation and two main trials. A low correlation ($r = -0.30$, $P = 0.516$) was found between total time (seconds) in the MART and mean sprint time (seconds) in the BST, indicating that a minimal relationship existed between the two protocols.

Reliability in previous studies examining RSA protocols has been frequently assessed using test-retest correlation coefficients (Baker et al. 1993; Fitzsimons et al. 1993). Using this approach significant correlations, $r = 0.86$ (Baker et al. 1993) and $r = 0.942$ (Fitzsimons et al. 1993), from two trials have been used to indicate that a test was reliable. However, Pearson's product moment correlation coefficient is not sensitive to changes in the mean between trials. It is feasible that on the retest all scores may be quicker, but a high correlation is still achieved. Moreover, correlation analysis is heavily influenced by the inter-subject variation.

Capriotti et al. (1999) have used a longitudinal model with six trials, to study the reliability of an intermittent high-intensity cycling protocol. The data was analysed using repeated measures ANOVA and a Neuman-Keuls post-hoc test. Capriotti et al. (1999) have reported that no significant difference was found between the mean power outputs for sprints 8–10, for trials held on days 2, 3, 4, 11 and 12.

Table 2 Mean average sprint times for the first two sprints and the last two sprints of all Bangsbo Sprint Test trials

Part of course (letters defined in Fig. 1)	Time (s)			
	Sprints 1 and 2		Sprints 6 and 7	
	Mean	SD	Mean	SD
Whole course (A–D)	7.551	0.319	7.735**	0.283**
First 10 m (A–B)	2.605	0.158	2.665**	0.127**
Middle section (B–C)	3.224	0.169	3.261*	0.171*
Last 10 m (C–D)	1.722	0.085	1.812**	0.086**

* Significant difference from the mean of sprints 1 and 2, at $P \leq 0.01$

** Significant difference from the mean of sprints 1 and 2, at $P \leq 0.001$

For the present study a repeated measures ANOVA showed that there was a significant difference between means of the six trials. A Tukey post-hoc test indicated that significant differences ceased after trial 2 (Table 1). The difficulties in calculating type II errors in post-hoc analysis in both the present study and the study of Capriotti et al. (1999), make it difficult to make a decision based upon confidence in the null hypothesis and the reliability of the test.

The CV for within-subject variation, across trials, offers an alternative calculation of reliability. Hopkins et al. (1999) advocated calculating a central CV (using the log transformed variables), which is accompanied by 95% CI for the population. The CV calculated in this way for all six trials in the present study was 1.8% (95% CI 1.5–2.4), suggesting a low level of within subject variability. The same calculation was made for the two trials of the MART, giving a CV of 2.1% (95% CI 1.4–4.7), suggesting that there is more within-subject variability in the MART than the BST. This central figure is invariably lower than the individual CV across a number of trials because it represents an average figure for the CV from test to test, not across all six tests.

The usefulness of the test-to-test CV is in determining the sensitivity of a test. Hopkins et al. (1999) used a technique which focuses upon the precision of estimation of the magnitude of effect, defined by 95% CI. The equation used for a random crossover trial is:

$$\mathrm{aCV} = t\mathrm{CV}\sqrt{2}/\sqrt{\mathrm{n}} \quad (2)$$

where aCV is the multiple of CV which represents the smallest worthwhile enhancement or decrement, e.g. 0.5CV, and t is the appropriate value of the t statistic. This can be algebraically converted to:

$$\mathrm{n} = (t\mathrm{CV}\sqrt{2}/\mathrm{aCV})^2 \quad (3)$$

For example the average CV value for trials 2–4, as calculated by the Hopkins et al. (1999) method, is 1.9% (95% CI 1.3–3.1), and over trials 4–6 is 1.4% (95% CI 1.0–2.3). Using Hopkins et al. (1999) equation, the influence this has over the sample size needed to detect a 1.0%-performance enhancement is to suggest an additional 11 subjects with only three familiarisations compared with five. With a lower performance enhancement fewer subjects or fewer familiarisation trials would be adequate.

To measure a component of fitness that is valid for a sport, it is necessary to recreate the activity of that sport as closely as possible. The energy demands of a sport such as soccer are complex and difficult to quantify. Typically authors have reported sprint distances of around 15 m and high:low exercise intensity ratios of about 1:8 (Reilly and Thomas 1976; Mayhew and Wenger 1985; Yamanaka et al. 1988). The sprint distance for the BST was 34.2 m, and the mean time taken to complete a sprint was 7.664 (SD 0.29) s. Thus, it would appear that the BST and similar protocols are not sport-specific. However, these mean data from match analyses do not reflect the variability of the time taken for individual bouts of high intensity exercise. Withers et al. (1982) showed that whilst the average distance covered by high intensity running during a soccer match is 22.4 m, and that the average time per high intensity exercise period is 3.7 s, the standard deviations were 15.7 m and 2.7 s, respectively. The study of Withers et al. (1982) further showed that the most physiologically demanding situation experienced by a player involved 11 consecutive periods of high intensity exercise, with a mean ratio of 1:3.1, which lasted for a period of 178.2 s. It is possible to see that the BST, where the mean ratio of high to low intensity exercise is 1:3.3, and the mean time taken is 203.6 (SD 2.03) s, is extremely close to representing a physiologically stressful part of the game. The BST may therefore be appropriate for assessing the periods of high intensity exercise that are critical to the outcome of the game.

A further problem with some of the match analysis studies is that in their attempts to be objective, they have used velocity for the quantification of effort. Bangsbo et al. (1991) used any running above the speed of $30 \text{ km} \cdot \text{h}^{-1}$ to represent sprinting. This may underestimate the energy cost, because as Hughes (1973) observed "players are frequently having to use energy to overcome inertia". With sprints of a short length, it is possible that the players never reach this speed, but have exerted a great deal of physiological effort.

Most RSA protocols involve unidirectional running and neglect the multidirectional nature of a sport like soccer. Withers et al. (1982) have shown that in Australian first division soccer, a player makes an average of 50 turns in a game. Reilly (1996) has shown that approximately 16% of the distance covered by players is by moving backwards, sideways or by "jockeying" for the ball. The changes in energy demand and muscle recruitment that result from this type of activity have not been well studied or understood. Reilly and Bowen (1984) showed that oxygen consumption was significantly higher for sideways and backwards movement, than for forwards running at the same speed. The difference increased disproportionately with velocity of movement. Therefore, any protocol that seeks accurately to assess RSA for soccer players must include multidirectional running. Of the protocols examined only the Bangsbo (1994) protocol has incorporated a vari-directional component, performed on a grass surface. The results from the present study show that there was no significant difference between sprint times that were along the left or right sections of the course. This seems to indicate that sprint direction has little influence over sprint time.

In assessing the validity of the BST it is necessary to make suppositions about the energetics that may be involved in performing the test. The consistency between the structure of the study by Gaitanos et al. (1993) and the BST suggest that metabolism during the two tests will be similar, although it should be noted that Gaitanos et al. (1993) used cycling exercise. The sprints in the BST were maximal, with a mean duration of 7.664 (SD 0.290) s. The study by Gaitanos et al. (1993) used a protocol involving ten maximal sprints of 6 s in duration, separated by 30 s recovery. Using data from muscle biopsies they estimated that during the first sprint an average of 49.6% of anaerobic adenosine triphosphate (ATP) production was derived from the breakdown of creatine phosphate (CP), and 44.1% from glycolysis. During the tenth sprint 80.1% of the anaerobic ATP production came from CP breakdown, as opposed to 16.1% from glycolysis. Total anaerobic ATP production during the final sprint was estimated to have been reduced to 35% of the levels estimated for the first sprint.

Given the similarity in the RSA protocols that have been described by Tumilty et al. (1988), Dawson et al. (1991), Baker et al. (1993), Fitzsimons et al. (1993), Bangsbo (1994), and Wadley and Le Rossignol (1999), it can be hypothesised that they all imposed a similar metabolic stress upon participants. The exception to this may be those protocols which have included a high number of sprints (Dawson et al. 1984; Nagahama et al. 1993; Hautier et al. 1998; Wadley and Le Rossignol 1998). Nagahama et al. (1993), using 20 repeated sprints, have found that the power output became asymptotic for elite and university division 1 subjects. Dawson et al. (1991) cited anecdotal evidence suggesting that "pacing" was occurring in a protocol with 20 repeated sprints. Based upon the results from seven subjects, it was viewed that the athletes were not sprinting maximally during all the sprints in an attempt to ensure completion of the test (Dawson et al. 1991). In addition to this, the findings of Gaitanos et al. (1993) indicate that the aerobic contribution towards ATP production is greater for the latter sprints. A high number of sprints in a RSA protocol may result in the increasing predominance of aerobic energy production, and a "pacing" of sprint efforts. If this were so, the test would concede some of its validity as a measure of RSA.

Significant differences were found for the split times over each segment of the course (Fig. 1, A–B, B–C, C–D). These results are consistent with Balsom et al. (1992) who reported that a 30 s recovery resulted in a decrease in velocity over the first and last 10 m of a 40 m repeated sprint protocol. Balsom et al. (1992) linked their findings to the work of Sahlin and Ren (1989) and hypothesised that both CP resynthesis and capacity to rephosphorylate adenosine diphosphate (ADP) were limited with a 30 s recovery, whereas with a 60 s recovery, resynthesis of CP was not a limiting factor.

A low correlation ($r = -0.298$, $P = 0.516$) was found between total running time in the MART and mean sprint time in the BST demonstrating a poor relationship between the two tests. Presently there is no accepted benchmark against which to establish the criterion validity of sprint tests. A variety of procedures have been used (Baker et al. 1993; Dawson et al. 1993). More recently the MART has received strong support as a measure of anaerobic performance since its intermittent nature more fully reflects movement patterns in many sports than a continuous test such as the Wingate, and it is based on running rather than cycling. The lack of a relationship between the BST and the MART questions the criterion validity of the BST. Nevertheless since all existing tests are indirect, that is, they rely on the measurement of external work rather than physiological strain, any conclusion must remain tentative.

In conclusion, the BST is logical and in context. It is more difficult to establish criterion validity because of the lack of a generally-accepted benchmark test that reflects the metabolism of sport-specific intermittent activity. In the present study correlation with the MART was low. The BST improved its reliability after three familiarisation sessions. Furthermore, in assessing the reliability of newly devised field tests, a rigorous longitudinal model is advised, that includes the calculation of a centralised CV.

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