Section I – Kinesiology

sciendo

The Reactive Bounding Coefficient as a Measure of Horizontal Reactive Strength to Evaluate Stretch-Shortening Cycle Performance in Sprinters

by
Jad Adrian Washif[1], Lian-Yee Kok[2]

Plyometric exercises such as drop jumping and bounding offer athletes a substantiated means of enhancing athletic performance. Between the two exercises, reactive measurement using bounding (reactive bounding coefficient [RBC]) has received scant attention within the domain of training and conditioning. Therefore, this study aimed to identify the viability of utilising a speed-bounding exercise to assess horizontal reactive strength. Eleven young, male elite sprinters (age: 17.8 ± 1.3 yr; body height: 1.72 ± 0.06 m; body mass: 66.05 ± 6.10 kg; best 100 m sprint time: 10.77 ± 0.32 s) were tested for static jumps (SJ), drop jumps (DJ), 10 speed-bounding (RBC10), and 50 m sprint performance. Between-group comparisons based on sprint ability (fast [FSG] vs. slow [SSG] sprint-group) and correlation coefficients were computed subsequently. The FSG (n = 5; 50 m time: 5.82 ± 0.11 s; RBC10: 7.46 ± 0.27) performed significantly better in the RBC10 (p = 0.036) than the SSG (n = 5; 50 m time: 6.09 ± 0.13 s; RBC10: 7.09 ± 0.25). A very high correlation was attained between the RBC10 and the criterion measure, the SJ (r = 0.83). Additionally, RBC10 appeared to be correlated with 30, 50, 10-30 and 30-50 m sprint times (r = -0.52 to -0.60). This positive trend, however, was not observed for the DJ reactive strength index (trivial to moderate correlations). Good reliability was shown for the RBC10 and all sprint distances (<1.5% coefficient variation). Furthermore, all sprinters attained ground contact times of 0.12-0.18 s during the RBC10 which was indicative of fast stretch-shortening cycles during movement, suggesting that the RBC10 could be utilised to assess plyometric ability and enhance sprint performance. Overall, the RBC10 seems able to discriminate between the FSG and the SSG, indicating it has acceptable levels of validity and reliability.

Key words: athletics, explosive, plyometric, power, speed-strength, sprinting.

Introduction

The stretch-shortening cycle (SSC) is a natural variation of muscle function found in conventional human movements. In sports, one common modality to improve SSC performance is through plyometric training. Plyometric training offers athletes an established and straightforward way to enhance athletic abilities (Chu, 1998). It originated from the Eastern bloc in the 1960's, and was named the 'shock method' by Yuri Verkhoshansky, who used it to develop explosive strength and speed in elite athletes (Verkhoshansky and Siff, 2009). Plyometric

exercises consist of hops, jumps, and bounds, and are utilised extensively by athletes involved in track and field, and other sports to improve skill execution, physical performance, and to reduce the risk of injury (Chu, 1998; Yessis, 2009). Plyometric exercises have also been used to assess SSC exercise performance and lower limb power. The countermovement jump (CMJ), static jump (SJ), drop jump (DJ), hopping, and bounding are the most commonly used movements to assess these qualities (Dobbs et al., 2015; McCurdy et al., 2010). Yet, when training or assessing individuals, exercise selection is critical as movement

[1] - *High-Performance Branch, National Sports Institute of Malaysia, Bukit Jalil, Malaysia.*

[2] - *Department of Sports Studies, Universiti Putra Malaysia, Serdang, Malaysia.*

specificity may influence the degree of the relationship and transference into performance (Cronin and Hansen, 2005; Young, 2006).

Regardless of the exercise choice, sprint performance relies on strength, power and stiffness of the leg muscles (Bret et al., 2002; Lockie et al., 2011), and also higher levels of reactive strength (Lockie et al., 2011). Moreover, having higher levels of musculotendinous leg stiffness increases the ability to absorb, store and release energy (Bret et al., 2002), allowing a spring-like action of the legs during the ground contact phase to encourage faster cadence and speed during sprinting (Harrison, 2010). This assertion corroborates with other findings (Nagahara et al., 2018) that highlight the importance of force production during maximal sprinting by indicating that better sprinting performance is concomitant with a large exertion of propulsive force during acceleration, lessened braking forces when approaching maximal speed, and a large vertical force during the maximal speed phase. Of note, force that is developed by the extensor muscles (gluteus maximus, vastus lateralis, rectus femoris and gastrocnemius) during the contact phase can influence kinematic variables such as step length (Coh and Tomazin, 2006). Furthermore, step length and frequency change throughout maximal sprinting, but more dynamically during the acceleration phase than the maximal velocity phase. In addition, decreased contact time, increased flight time and step length are associated with better maximal speed performance (Lockie et al., 2011).

Compared to other forms of exercise, bounding can provide specificity for sprinting due to its ability to generate great propulsive horizontal forces with a short contact time which is important for production of high levels of power (Mero and Komi, 1994). Furthermore, bounding emphasises the role of the rectus femoris muscles during the forward leg swing (Mero and Komi, 1994), which is critical for producing forward accelerative forces (Mero et al., 1986). Also, this exercise is usually performed unilaterally and repetitively, replicating actual sprinting movements, unlike other exercises performed vertically and horizontally (Maćkała et al., 2015). Consequently, 'sprint bounding' (a combination of sprinting and bounding) was deemed to be appropriate as a training method

for improving sprint performance, and also for assessing the 'sprint bound index' (SBI) (Young, 1992). The calculation of the SBI is performed by totalling the number of bounds completed within 30 m, and multiplying the score by the time taken to complete the distance (Young, 1992). However, the use of hand-held devices to measure time and the approximation of distance (counted to the nearest half bound) during the scoring of the SBI in previous literature (Young, 1992) could have limited test accuracy and sensitivity.

In order to overcome the previous limitations, a reactive bounding coefficient (RBC) is proposed in this study. The measurement of the RBC utilises a camera to record the time taken to complete a predetermined number of bounds (e.g. 10), while the distance covered is visually ascertained. The RBC also takes into consideration individual leg length to scale each person's distinct ability to use their SSC or explosiveness. These considerations may increase the diagnostic value of the RBC. With this in mind, the purpose of this study was to identify the viability of the RBC10 (RBC with 10 bounds) to assess horizontal reactive strength in highly-trained young sprinters. Additionally, this study sought to examine the relationship between the RBC and sprint performances.

Methods

Participants

This study involved 11 young male track and field sprinters who participated in 100 to 400 m track events (Table 1), and had experience competing in age-group, youth or senior national, and international level championships. Additionally, they had been participating in sprint and plyometric training regularly for 2-4 years. All participants, as well as their coaches, were informed about the study's objectives, procedures, and they understood the risks and benefits of participation. Written informed consent was obtained from participants or their legal guardians (for participants < 18 yr old), to undertake all test sessions. The study was conducted in accordance with high ethical standards, against exploitation of human participants, to ensure all procedures and protocols were appropriate, and followed the guidelines of the World Medical Association's Declaration of Helsinki (World Medical

Association, 2013), and the ethical standards in sport and exercise science research (Harriss and Atkinson, 2015). This study was approved by the institutional Review Board of the National Sports Institute of Malaysia.

Design and Procedures

To determine if the RBC10 was an acceptable test for horizontal reactive strength, two validity assessments were carried out. The first validation assessment (n = 11) involved a correlation between the RBC10 with a criterion measure, the SJ (Cronin and Hansen, 2005; Washif and Kok, 2017). The second validation assessment compared the RBC10 scores between sprinters of different ability levels to verify the discriminatory capability of the new test. To achieve this, the sprinters were ranked from 'fastest' to 'slowest' and then the one ranked 6th was removed in order to establish two groups with a more distinct difference in sprint performances. To test the relationship between the RBC10 and sprint performances, the total sprint time, acceleration, and maximal speed were considered during analysis. Participants attended a total of four testing sessions, with the first two arranged on the same day, and separated by 5 hours, while the third and fourth sessions were conducted separately over the next two days. A brief familiarisation session was conducted two days prior to the first experimental session.

Testing took place at the commencement of the participants' new preparation phase, following several weeks of a maintenance phase. Participants rested for 24 hours prior to the start of the first testing session. They were instructed to attend the four testing sessions in a fed and hydrated state. Except for the DJ and SJ tests that were carried out in a gym, all other tests were conducted on an outdoor synthetic running track familiar to participants. Participants performed the tests in the following order: Day 1, morning - anthropometric measurements; Day 1, afternoon - DJ, SJ and RBC tests; Day 2, afternoon - 50 m and 300 m sprints; Day 3, afternoon – the maximal half-squat strength test.

The DJ test was conducted after a 20-min warm up which included dynamic stretching and sub-maximal vertical jumps, which was followed by two warm up trials on a force plate (400 Performance Series, Fitness Technology, Adelaide, Australia). The ground reaction force data were sampled at 600 Hz. Each participant began the test by standing on a 35-cm box with arms akimbo. He then stepped off forward onto a force plate and performed a countermovement jump. Participants were asked to minimise ground contact time and maximise jump height. Kinematic parameters such as ground contact time and flight time were obtained. Flight time was used to determine jump height, while jump height was divided by ground contact time to obtain a reactive strength index (RSI) value.

During the SJ, participants were required to descend by flexing their hips and knees until an angle of approximately 90° was formed at the knees. This position was held for three seconds. Upon receiving instruction from the tester, participants immediately performed an explosive vertical jump by extending the hips and knees. A trial was repeated if pre-stretch movement was spotted prior to the upward jump. This was visually monitored from the resultant force-time data on the screen of a computer that was connected to the force plate. Three trials were separated by a rest interval of 60 s.

For the RBC, participants were asked to begin the test by standing with their toes on a starting line and were then asked to perform 10 unilateral horizontal jumps (bounds) in succession (RBC10). Participants were encouraged to complete the jumps as quickly as possible while trying to maximise the distance. A run-up was not permitted, but pre-stretch movements and arm swings were accepted. The participant was allowed to start with any foot in front of the starting line. Two trials were allowed with a 6-8 min rest interval in between for each participant. A trial was deemed satisfactory if a participant did not run or fall down. Otherwise, the trial would be repeated. Furthermore, participants were asked to perform 'regular or normal performance' during the tests which involved bounding along a straight-line, with the body executing antero-posterior translation when transitioning from the foot contact to the take-off, and to the subsequent foot contact, without displaying side-to-side movements. To observe the required accurate execution of these movements, all bounds were filmed from the front using a camcorder (Sony HDR-PJ50, Tokyo, Japan, 25 Hz).

Analysis was then performed using

motion analysis software (Kinovea 0.8.15) to calculate the time taken to complete 10 bounds. Time started from the last seen contact point between the edge of the front shoe with the track surface at the initiation of the first step, and ended when any part of the toe or heel touched the track surface to complete the last (tenth) step. The distance was measured to the nearest 0.5 cm using a tape measure from the starting line to the rear edge of the foot during the final landing position (Figure 1). The person assessing the landing stood at the side of the expected final landing position that was previously identified during familiarisation. Data from familiarisation and previous tests were also used to determine the minimum and maximum distances to be considered for further analysis. Achieving distances shorter than 22 times a participant's leg length was considered 'sprinting', while achieving distances longer than 30 times a participant's leg length was considered 'bounding-for-distance'. The '22 times of a participant's leg length' would approximate a distance of less than 20 m for participants, which was achieved when the instruction given was 'bound as fast as possible'. The '30 times a participant's leg length' would match a distance of approximately 27 m that was achieved, on average, by sprinters when the instruction given was 'bound as far as possible'. This distance-focus task sometimes altered the mechanics of foot landing, where heels made the first contact with the ground (i.e. this technique was called 'stepping'), thus promoting higher braking impulses, instead of using the ball of the foot as in speed-bounding (Mero and Komi, 1994). To overcome this issue, data from each trial were compared to that participant's acceptable range, failing which, a trial was repeated. Leg length was measured from the anterior superior iliac spine to the tip of medial malleolus. The RBC was determined by dividing the bounding distance (in metres) with the total time (in seconds) to obtain the average velocity (m·s^{-1}). This value was then divided by the number of bounds (i.e. 10) to obtain a single-bound average (1Tread) value which was then divided by the leg length (m), and then multiplied by the number of bounds (i.e. 10) to obtain the relative RBC10 value.

During the sprint tests, participants were asked to perform two 50 m sprints at maximum effort, separated by a 10-min rest interval. Sprint times were captured via dual-beam infrared timing lights (Swift Performance Technologies, Australia). Participants used a crouch start from starting blocks placed 50 cm behind the first set of timing gates positioned at a height of 0.5 m. The other sets of timing gates were located 10 and 30 m from the starting line placed approximately at the hip-waist level. This allowed the collection of acceleration and maximal speed data at 10-30 m and 30-50 m, respectively. After the second trial, a 30-min recovery was given before a single 300 m all-out time trial was performed, using the same procedures. Participants were well acquainted with both sprint tests.

Statistical Analyses

Data were initially analysed with descriptive statistics, and results were reported as means ± SD. Normality of data was assessed using Shapiro-Wilk statistics and normal Q-Q plots. To assess the repeatability of performances between trials, intraclass correlation coefficients (ICC) were used for test-retest reliability of the DJ and SJ, whereas Pearson correlation was utilised to analyse relationships between jump and sprint variables with the RBC10, and to assess validity and reliability. Strength of correlations was considered trivial if r was < 0.10, small if r was 0.10-0.29, moderate if r was 0.30-0.49, large if r was 0.50-0.69, very large if r was 0.70-0.89, and nearly perfect if r was 0.90-0.99 (Hopkins, 2002). Additionally, independent t-tests were used to examine differences between the FSG and the SSG, while the between-trial coefficient of variation (CV), and 95% confidence intervals (CI) were calculated as measures of variability. Significance was accepted when $p \leq 0.05$. All analyses were performed using a statistical software package (SPSS version 16.0; SPSS Inc., Chicago, IL, USA).

Results

Results from the Shapiro-Wilk test and visual inspection of the Q-Q plots found distribution to be normal for all variables ($p > 0.05$). Test-retest reliability for all sprint distances up to 50 m ($r = 0.95$ to 0.99), the RSI ($r = 0.94$) and the SJ ($r = 0.96$) was very high. Furthermore, test-retest reliability for the RBC10 was acceptable ($r = 0.79$). A very strong and significant relationship was obtained between the RBC10 and SJ peak power ($r = 0.83$, $p = 0.003$), indicating the RBC10 as a valid explosive

performance measure (Figure 2). Meanwhile, significant differences were found between the FSG and the SSG for the 50 m sprint ($p = 0.013$) and the RBC10 ($p = 0.036$) (Table 3). Correlational measures found that the RBC10 attained greater relationships with sprint performance (r = -0.29 to -0.60) than with the RSI from the DJ ($r = 0.01$ to -

0.47), with the exception of the 300 m sprint, which achieved a lower magnitude score (Table 4). However, no significant relationships ($p > 0.05$) were observed for all strength indices and sprint times. The summary of the results for the jump tests is shown in Table 2.

Figure 1

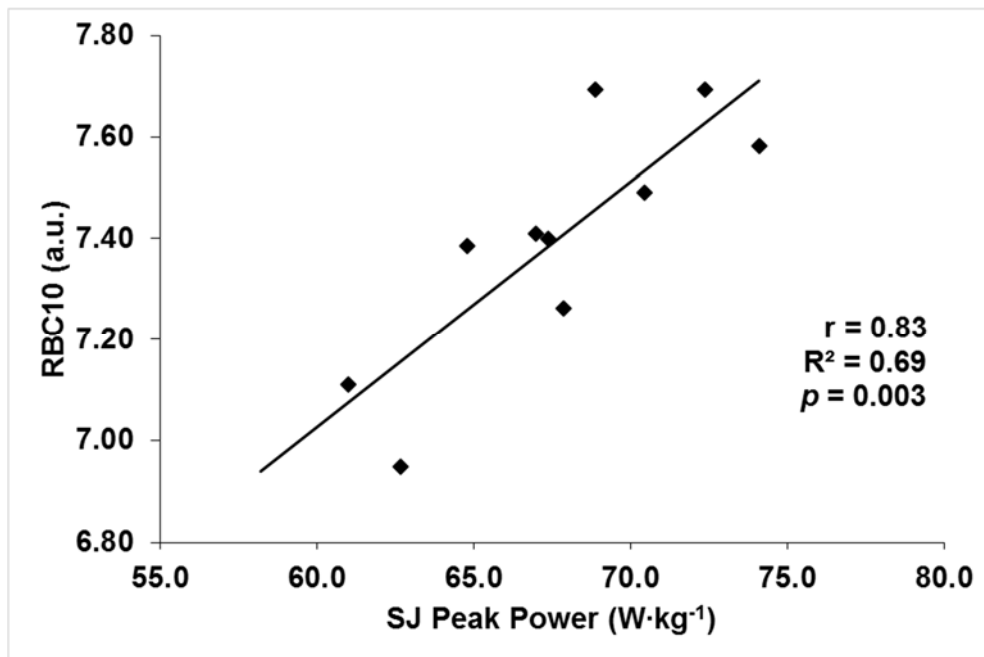*Schematic representation of measurements*

Figure 2

Correlation between the RBC10 and relative peak power of the static jump (SJ).
RBC10 = reactive bounding coefficient with 10 bounds.

Table 1

Descriptive characteristics of participants.

Variables	Mean ± SD (n = 11)		
Age (y)	17.8 ± 1.3	Drop jump CT (s)	0.159 ± 0.01
Body height (m)	1.72 ± 0.06	Drop jump JH (m)	0.535 ± 0.04
Body mass (kg)	66.05 ± 6.10	Speed-bounding distance (m)	22.30 ± 1.43
Body Mass Index (kg·m²)	22.29 ± 2.18	Speed-bounding CT (s)	
100 m best time (s)	10.77 ± 0.32	*1st bound*	0.180 ± 0.02
Relative 1RM half-squat (kg·kg⁻¹)	1.86 ± 0.20	*5th bound*	0.131 ± 0.01
Leg length (m)	0.91 ± 0.03	*10th bound*	0.122 ± 0.01

RM = repetition maximum; CT = contact time; JH = jump height.
All characteristics except 100 m best time were measured from the present study.

Table 2

Mean (± SD) best trials and test-retest agreement of variable measures.

Main variables	Mean ± SD	Min	Max	95% CI	ICC / r	CV, %
RSI (drop jump) (a.u.)	2.20 ± 0.30	1.73	2.50	1.99-2.42	0.94	5.0
RBC10 (a.u.)	7.40 ± 0.24	6.95	7.69	7.26-7.61	0.79	1.4
10 m sprint (s)	1.72 ± 0.04	1.64	1.80	1.69-1.75	0.95	0.6
30 m sprint (s)	3.90 ± 0.09	3.84	4.05	3.85-3.98	0.98	0.6
50 m sprint (s)	5.93 ± 0.15	5.65	6.23	5.84-6.07	0.98	0.7
10-30 m flying (s)	2.18 ± 0.06	2.07	2.29	2.14-2.23	0.99	0.6
30-50 m flying (s)	2.02 ± 0.08	1.93	2.20	1.98-2.10	0.98	1.0
300 m sprint (s)	35.42 ± 1.28	33.73	36.91	34.65-36.32	n/a	n/a

RSI = reactive strength index; RBC = reactive bounding coefficient; CI = confidence interval;
ICC = intraclass correlation coefficient; r = Pearson correlation; CV = coefficient variation

Table 3

Main variables comparison between FSG and SSG (mean ± SD).

Main variables	FSG (n=5)	SSG (n=5)	*p* value	Effect size	Descriptor
50 m sprint (s)	5.82 ± 0.11	6.09 ± 0.13†	0.013	2.2	Large
RBC10 (a.u.)	7.46 ± 0.27	7.07 ± 0.22†	0.036	1.6	Large

† Significantly different (p < 0.05)
FSG = fast sprint group; SSG = slow sprint group

Table 4

Correlation among reactive strength indices and sprint performances and strength of magnitude

Sprint performances	RSI		RBC10		*p**
10 m sprint	0.01	Trivial	-0.28	Small	0.402
30 m sprint	-0.08	Trivial	-0.53	Large	0.093
50 m sprint	-0.30	Moderate	-0.59	Large	0.059
10-30 m flying	-0.12	Small	-0.60	Large	0.054
30-50 m flying	-0.47	Moderate	-0.52	Large	0.102
300 m sprint	-0.31	Moderate	-0.21	Small	0.544

*values for the RBC10
RSI = reactive strength index; RBC = reactive bounding coefficient

Discussion

The primary aim of this study was to examine the viability of using the RBC10 to assess plyometric ability, and also to investigate the influence of the RBC10 on sprint performance. Validity analysis indicated that the FSG outperformed the SSG in the RBC10 and this suggests that the test is able to discriminate between athletes of different sprint ability. Supporting this further is that the RBC10 is very strongly and significantly related (Figure 2) to relative peak power during the SJ (i.e. criterion measure), which implies that the RBC10 depends on explosive ability, making it a valid estimate of explosive performance such as that developed during the SJ (Chamari et al., 2008). The relationship between the RBC10 and sprint performance was generally positive (with some approaching significance), and the magnitude of the relationship was higher than that with the RSI (Table 4) unlike in previous studies (Barr and Nolte, 2011; Čoh and Mackala, 2013; Hennessy and Kilty, 2001; Washif and Kok, 2017) that have reported moderate to large relationships between the RSI and maximal sprint performances. Large correlations were found between the RBC10 and sprint distances involving maximal speed. However, this was not observed during the early acceleration phase (i.e. 10 m) nor during the longer sprint distances (i.e. 300 m).

What can be postulated from the current results is that while early acceleration requires a high level of explosive force exerted against the ground, performance of early acceleration (10 m) was not clearly distinguished between sprinters of the two ability levels (Maćkała et al., 2015). However, marked differences in acceleration between these two groups are only manifested in the later part of, or throughout the entire acceleration phase. The reason for these results may be related to reduced or increased variance between variables within the RBC10 and early acceleration or maximal speed. What may be important to note is that the magnitude of a relationship is dependent upon the standard deviation of the tested population. A large standard deviation is generated when the variation between the best and worst values is large, thus generating a strong correlation. Regardless of this, a clear outcome of this study is that the RBC10 was better than the RSI for assessing explosive and reactive strength.

Test-retest reliability analysis showed high repeatability for all variables except the RBC10 (Table 2), but the value achieved was acceptable. Nonetheless, the variations for all trial-to-trial measures were <1.5% indicating a small variation in the measurements (Hopkins, 2000), with exception for the RSI (5.0%). The lower test-retest repeatability seen for the RBC10 may be because this test involves only two trials rather than three, which is better for enhancing noise reduction, and therefore improving test-retest reliability. Additionally, the horizontal repetitive bounding used to obtain RBC10 scores seems to utilise optimal movement projections to maximise distance while minimising contact time, which helps performers achieve a higher unit of the RBC. These two factors may have collectively led to lower agreement in reliability values above.

The DJ RSI test has been widely used as a measure of reactive strength during performance (Byrne et al., 2017; Cronin and Hansen, 2005). This test emphasises shorter ground contact and maximum jump height which were thought to promote reflex potentiation and elastic energy recoil (Komi and Bosco, 1978). Hence, higher levels of reactive strength may be translated to better sprint performance as both variables emphasise a rapid SSC. However, the RSI test's heavy dependence on ground contact time may not be favourable (Barr and Nolte, 2011) as it may be unable to differentiate between athletes who are "contact time" dominant and those who are "jump height" dominant (Byrne et al., 2017). Thus, it was suggested to utilise optimal drop height for each individual as opposed to a default drop height (as used in this study) when addressing the DJ RSI (Byrne et al., 2017). Irrespective of the previous statement, a previous study found a moderate relationship between the RSI and sprint speed, it also noted that DJ height had a stronger correlation than the RSI (Barr and Nolte, 2011). This could explain why the RSI values from the vertical DJ in this study were not higher than those of the RBC10. However, literature seems equivocal regarding a strong relationship between the RSI and sprinting speed (Hennessy and Kilty, 2001), but correlation was low between the RSI, early acceleration and maximal velocity (Young et al., 1995). Furthermore, in highly trained young sprinters, the RSI was strongly related to maximal

velocity, but not acceleration (Washif and Kok, 2017). This trend is somewhat similar to what was seen in the RBC10 in the present study, although it seems that the RBC10 was more advantageous than the RSI for sprint performances (Table 4).

Unlike the vertical jump (i.e. the DJ in the current study), the influence of reactive strength using horizontally-directed hopping on sprint performance has not been thoroughly investigated. It was reported that double-legged horizontal jumps, the standing long jump, 5-jumps, and 10-jumps were strongly correlated with speed during 10, 30, and 100 m sprints (Maćkała et al., 2013). Although field-based assessments are necessary, forward jumping for displacement may not be a true measure of reactive strength as time is not utilised during computation, but reactive strength is the ability to exert maximal forces in the shortest time possible (Zatsiorsky and Kraemer, 2006). In addition to this, it has been observed that kinetic and kinematic measures of double-legged reactive horizontal jumping correlated unconvincingly with sprint performances over short distances (Moresi et al., 2011). Nevertheless, for non-sprinter samples, the unilateral horizontal jump for distance seems to be reliable and predictive of short sprint ability (Holm et al., 2008; Stålbom et al., 2007).

The other reasons for the higher correlation between the RBC10 and sprint performance may be explained from different perspectives. First, the RBC (i.e. speed bounding) involves a considerable degree of eccentric action that may occur during the landing phase of the sprint action. Furthermore, sprinting involves muscle preloading during the eccentric phase, horizontal and vertical propulsive forces, and unilateral propulsion (Stålbom et al., 2007). During sprinting, these movements need to be performed repetitively, and the RBC seems to be able to fulfil all criteria as a test compared to other strength indices. The RBC also emphasises displacement, fast contact time, and initial contact at the forefoot, as occurs in maximal sprinting (Mero and Komi, 1994). Moreover, the continuous reduction of average contact time (first step was ~0.18 s, and then ~0.13 s and ~0.12 s in the 5th and 10th steps, respectively) reflects the actual acceleration into the maximal-speed pattern during sprinting. The contact times observed were less than the threshold contact time of 0.250 s which implies fast SSC performance (Schmidtbleicher, 1992). The SSC is integral to plyometric exercise because it enhances the ability of the muscle-tendon unit to produce maximal force in the shortest amount of time (Komi, 2003; Saez de Villarreal, 2012). The key mechanism of the SSC is efficient preactivation (i.e. 100 ms prior to contact) of agonists and synergists of the ankle joint such as the gastrocnemius, soleus, and tibialis muscles (Čoh and Mackala, 2013; Gollhofer and Kyröläinen, 1991). This activation leads to increased ankle joint stiffness, which can facilitate the function of flexors and extensors in the ankle before contact with the ground (Gollhofer and Kyröläinen, 1991). Hypothetically, training to improve the SSC using bounding exercise can enhance the velocity and frequency of the take-off during sprinting, which is decisive for fast ground contact and sprint performance. This can be facilitated by enhanced reflex potentiation and the efficient use of stored elastic energy as a result of plyometric training (Komi and Bosco, 1978), which also explains the better sprint times and the RBC10 in the FSG as compared to the SSG in this study. Moreover, a training programme incorporating more horizontal acceleration such as bounding exercise may improve sprint times to a greater degree than vertical plyometrics alone (Saez de Villarreal, 2012).

A test that is performed in a way that mimics sprint performance such as the horizontal jump may be more meaningful to sprinters (Ball and Zanetti, 2012; Hunter et al., 2005) as it may have more mechanical specificity such as muscle contraction and vector or directions that can influence the values of the RBC. In conclusion, this study found that the RSI produced low to moderate correlations with all sprint distances, while the RBC10 produced stronger correlations with shorter sprint distances. Despite insignificant correlations, the data from this study demonstrated that the RBC10 was better than the RSI in explaining sprint performance at varying distances. This study, however, is not without limitations; the sample size was relatively low (n = 11), making generalisation of the results difficult. Nevertheless, this study involved a group of homogenous and elite young sprinters, which in turn, may provide a representation to a similar group of well-trained sprinters. Including a large

sample of elite athletes has always been challenging for researchers, but the high level of reliability (i.e. low variation) may indicate that the RBC test is able to detect small changes in performance, thus allowing smaller sample sizes to be used (Hopkins, 2000). Moreover, this study could have significant implications for strength and conditioning professionals due to its emphasis on direction-specific movements such as horizontal jumps, leg alternations, and also balance and coordination between the lower and upper limbs during the bounding task. As a test, the RBC is highly specific to sprinting and may have prognostic and diagnostic values, but a longitudinal study should be conducted to observe the changes of the variables over time. Future research should also examine inter- or intra-day reliability of the RBC, validate the use of smartphones for assessment of the RBC and also to obtain a range of normative data for the RBC. As a final note, the RBC10 is sensitive to different levels of sprint ability, and could be used to discriminate between faster and slower sprinters.

Practical Implications

As the RBC resembles sprint running and was found in this study to be valid and reliable, and is correlated with sprint performance of varying distances, it can be used to assess the ability to utilise the SSC and to monitor sprint performance. Given the non-homogeneity of participants' competition achievements, the average data of the RBC10 for higher ability sprinters were identified, and the value of ≥7.5 a.u. seems suitable to represent a sprinter with good ability to utilise the SSC during the unilateral-horizontal and repetitive jumping, while a value of ≤7.1 a.u. may be interpreted as a below average score. Further investigation is needed to provide normative RBC data. Currently, it seems that coaches can consider using the bounding exercise for training and the RBC10 to evaluate plyometric ability.

References

Ball NB, Zanetti S. Relationship between reactive strength variables in horizontal and vertical drop jumps. *J Strength Cond Res*, 2012; 26(5): 1407-1412. doi: 10.1519/JSC.0b013e3182510870.

Barr MJ, Nolte VW. Which measure of drop jump performance best predicts sprinting speed? *J Strength Cond Res*, 2011; 25: 1976-1982. doi: 10.1519/JSC.0b013e3181e4f7ba

Bret C, Rahmani A, Dufour AB, Messonnier L, Lacour JR. Leg strength and stiffness as ability factors in 100 m sprint running. *J Sports Med Phys Fitness*, 2002; 42(3): 274-281

Byrne DJ, Browne DT, Byrne PJ, Richardson N. Interday reliability of the reactive strength index and optimal drop height. *J Strength Cond Res*, 2017; 31(3): 721-726. doi: 10.1519/JSC.0000000000001534

Chamari K, Chaouachi A, Hambli M, Kaouech F, Wisløff U, Castagna C. The five-jump test for distance as a field test to assess lower limb explosive power in soccer players. *J Strength Cond Res*, 2008; 22(3): 944-950. doi: 10.1519/JSC.0b013e31816a57c6

Chu D. *Jumping Into Plyometrics.* 2nd ed. Champaign, IL: Human Kinetics; 1998

Coh M, Tomazin K. Kinematic analysis of the sprint start and acceleration from the blocks. *New Stud Athletics*, 2006; 21: 23-33

Čoh M, Mackala K. Differences between the elite and sub elite sprinters in kinematic and dynamic determinations of countermovement jump and drop jump. *J Strength Cond Res*, 2013; 27(11): 3021-3027. doi: 10.1519/JSC.0b013e31828c14d8

Cronin JB, Hansen KT. Strength and power predictors of sports speed. *J Strength Cond Res*, 2005; 19(2): 349-357

Dobbs CW, Gill ND, Smart DJ, McGuigan MR. Relationship between vertical and horizontal jump variables and muscular performance in athletes. *J Strength Cond Res*, 2015; 29(3): 661-671. doi: 10.1519/JSC.0000000000000694

Gollhofer A, Kyröläinen H. Neuromuscular control of the human leg extensor muscles in jump exercises under various stretch load conditions. *Int J Sports Med*, 1991; 12(1): 34-40

Harrison AJ. Biomechanical factors in sprint training: where science meets coaching. *Int Symp Biomech Sports*, 2010; 28: 36-41

Harriss DJ, Atkinson G. Ethical standards in sport and exercise science research: 2016 update. *Int J Sports Med*, 2015; 36(14): 1121-1124. doi: 10.1055/s-0035-1565186

Hennessy L, Kilty J. Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *J Strength Cond Res*, 2001; 15(3): 326-331

Holm DJ, Stålbom M, Keogh JW, Cronin JB. Relationship between the kinetics and kinematics of a unilateral horizontal drop jump to sprint performance. *J Strength Cond Res*, 2008; 22(5): 1589-1596. doi: 10.1519/JSC.0b013e318181a297

Hopkins WG. A scale of magnitudes for effect statistics. In: *A new view of statistics.* Available at: http://www.sportsci.org/resource/stats/effectmag.html; accessed on 15.12.2017

Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med*, 2000; 30(1): 1-15

Hunter JP, Marshall RN, McNair PJ. Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *J Appl Biomech*, 2005; 21(1): 31-43

Komi PV. Stretch shortening cycle. In: Komi P, eds. *Strength and Power in Sports.* Oxford: Blackwell Science; 2003: 184-202

Komi PV, Bosco C. Utilization of stored elastic energy in men and women. *Med Sci Sports*, 1978; 10(4): 261-265

Lockie RG, Murphy AJ, Knight TJ, Janse de Jonge XA. Factors that differentiate acceleration ability in field sport athletes. *J Strength Cond Res*, 2011; 25(10): 2704-2714. doi: 10.1519/JSC.0b013e31820d9f17

Maćkała K, Fostiak M, Kowalski K. Selected determinants of acceleration in the 100m sprint. *J Hum Kinet*, 2015; 45: 135-148. doi: 10.1515/hukin-2015-0014

McCurdy KW, Walker JL, Langford GA, Kutz MR, Guerrero JM, McMillan J. The relationship between kinematic determinants of jump and sprint performance in division 1 women soccer players. *J Strength Cond Res*, 2010; 24(12): 3200-3208

Mero A, Komi P. EMG, force, and power analysis of sprints specific strength exercises. *J Appl Biomech*, 1994; 10: 1-13

Mero A, Luhtanen P, Komi PV. Segmental contribution to velocity of centre of gravity during contact at different speeds in male and female sprinters. *J Hum Mov Stud*, 1986; 12: 215-235

Moresi MP, Bradshaw EJ, Greene D, Naughton G. The assessment of adolescent female athletes using standing and reactive long jumps. *Sports Biomech*, 2011; 10(2): 73-84. doi: 10.1080/14763141.2011.569564

Nagahara R, Mizutani M, Matsuo A, Kanehisa H, Fukunaga T. Association of sprint performance with ground reaction forces during acceleration and maximal speed phases in a single sprint. *J Appl Biomech*, 2018; 34(2): 104-110. doi: 10.1123/jab.2016-0356

Saez de Villarreal E, Requena B, Cronin JB. The effects of plyometric training on sprint performance. A meta-analysis. *J Strength Cond Res*, 2012; 26(2): 575-584

Schmidtbleicher D. Training of power events. In: Komi P, eds. *Strength and Power in Sports.* Oxford: Blackwell Scientific Publication; 1992: 381-395

Stålbom D, Holm, DJ, Cronin JB, Keogh J. Reliability of kinematics and kinetics associated with horizontal single leg drop jump assessment: A brief report. *J Sports Sci Med*, 2007; 6(2): 261-264

Verkhoshansky Y, Siff MC. *Supertraining: Expanded Version.* 6th ed. Rome: Verkhoshansky; 2009

Washif JA, Kok LY. Relationship between ballistic strength metrics and sprint performance in well-trained sprinters. *J Strength Cond Res*, 2017; 31(S1): S171

World Medical Association. *Declaration of Helsinki: Ethical principles for medical research involving human participants.* Adopted by the 18th WMA General Assembly, Helsinki, Finland, June, 1964, and amended by the 64th WMA General Assembly, Fortaleza, Brazil, October 2013

Yessis M. *Explosive Plyometrics.* Ultimate Athlete Concepts; 2009

Young W. Sprint bounding and the sprint bound index. *Strength Cond J,* 1992; 14(4): 18-22

Young WB. Transfer of strength and power training to sports performance. *Int J Sports Physiol Perform,* 2006; 1(2): 74-83

Young W, McClean B, Ardagna J. Relationship between strength qualities and sprint performances. *J Sports Med Phys Fitness,* 1995; 35(1): 13-19

Zatsiorsky V, Kraemer WJ. *Science and Practice of Strength Training*. 2nd ed. Champaign, IL: Human Kinetics; 2006

Corresponding author:

Jad Adrian Washif
High-Performance Branch,
Sports Performance Division,
National Sports Institute of Malaysia
National Sports Complex,
57000 Bukit Jalil
Kuala Lumpur, Malaysia
Phone: 03-8991 4942
Email: jad@isn.gov.my