Physical and Physiological Response to Different Modes of Repeated Sprint Exercises in Basketball Players

by
Rūtenis Paulauskas¹, Paulius Kamarauskas², Ričardas Nekriošius³, Nicholas Malcolm Bigwood⁴

The aim of this study was to investigate changes in physical and physiological responses to different modes of repeated sprint exercise by measuring speed, total time (sum of sprints), fatigue index, heart rate, local oxygen saturation, total haemoglobin content, and blood lactate. The volume of the physical load (distance, work and rest ratio) was the same in both exercises, but load specifics were different. The first mode consisted of 10 x 30 m sprints (with one change of direction) interspersed with 30 s of passive recovery, while the second mode of 20 x 15 m shuttle sprints interspersed with 15 s of passive recovery. Both exercise modalities were repeated three times with a five-minute rest interval between bouts with 7 days of recovery between each testing condition. Twelve highly trained male basketball players volunteered to participate in this study. Our study showed that different modes of repeated sprint exercises elicited a different physical response and metabolic demand. Longer sprints with directional changes placed a higher demand on the anaerobic glycolytic system compared to straight and more frequent sprint exercises. However, players' fatigue was more noticeable in shorter and more frequent sprints. Heart rate responses and local use of O₂ showed a similar activity of aerobic reactions through the different exercises. During the sprints, players’ SmO₂ fell to 40% and recovered to the level of about 80% during passive rest intervals without showing differences in both modalities. This suggests that both types of sprint exercises can similarly stimulate aerobic metabolism.

Key words: local oxygen saturation, blood lactate, heart rate, speed, fatigue index.

Introduction
Basketball players cover about 4500 – 5000 m during a game (Taylor, 2003). Players sprint every 21 s on average and make about 100 high intensity actions of short duration (e.g. jumping or sprinting) for about 34% of the game time (Narazaki et al., 2009). In-game performance has been generally stated to be related to the volume (e.g. distance travelled) of work rather than intensity (e.g. pace) of work, with a resulting lack of emphasis on intense exercises in training.

Rodriguez-Alonso et al. (2003) examined physiological demands of competitive basketball, using blood lactate concentration (BLa) and sustained high heart rate (HR) response, showing that despite the relatively small fraction of game time spent in high-intensity activities, the physiological demands were remarkably high. This previous research allows us to simulate workout loads and choose the most appropriate assessment methods. Field tests with tasks including basketball-like movements (jumping, sprinting) are becoming more relevant. The ability to repeat multiple high-speed sprints plays a crucial role in basketball players’ performance (Narazaki et al., 2009). Indeed, repeated sprint ability (RSA) is an important fitness component of

1 - Education Academy, Vytautas Magnus University, Vilnius, Lithuania.
2 - Faculty of Sport Biomedicine, Lithuanian Sports University, Kaunas, Lithuania.
3 - Faculty of Sport Biomedicine, Lithuanian Sports University, Kaunas, Lithuania.
4 - College of Medicine and Veterinary Medicine, Edinburgh Medical School, University of Edinburgh, Edinburgh, United Kingdom.

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team-sport athletes performance (Spencer et al., 2005). To design a specific conditioning program, an understanding of important physiological mechanisms is crucial. RSA has been validated and identified as a reliable index of physical performance in basketball players (Castagna et al., 2007). The ability to maintain each sprint at high intensity without dramatic decrement can be a good predictor to differentiate between athletes of different levels (Gabbett, 2007). As RSA has become a validated capacity assessment tool, repeated sprint exercises remain an attractive basketball training strategy.

Due to the relatively short sprinting periods in basketball (≤10 s), most energy contributing to RSA performance comes from the phosphocreatine (PCr) and the fast glycolysis systems (Turner and Stewart, 2013). In addition, research shows that the ability to resynthesize adenosine triphosphate and PCr during Repeated Sprint Exercises (RSE) may have a significant influence on RSA (Spencer et al., 2005). Hence, an individual with better aerobic fitness and a faster PCr-resynthesis rate during the recovery phase may perform better during RSE (Girard et al., 2011). Girard et al. (2011) showed a moderate correlation (.62 < r < .68; p < .05) between VO2max and RSA performance (mean sprint time and sprint decrement). However, Castagna et al. (2007) showed no statistically significant relationship between aerobic capacity and RSA indices. Despite a number of previous studies, conclusions regarding aerobic demands of RSE are limited.

Near-infrared spectroscopy (NIRS) is a non-invasive method for measuring localised blood flow and oxygenation. The process is based on the differential proportion of wavelengths which are absorbed by oxygenated and deoxygenated Hb (De Blasi et al., 1993). The validity of the NIRS method has been demonstrated through its strong correlations with venous O2 saturation (SmO2) at rest and during exercise (r = 0.92) (Mancini et al., 1994), and based on the reproducibility of its measurements during repeated incremental running (r = 0.87–0.88) and cycling (r = 0.94–0.99) tests to exhaustion (Austin et al., 2005). SmO2 measurement inversely correlates with VO₂ (r = −0.7) during trail running on hilly terrain (Born et al., 2016). To our knowledge, no direct measurement of SmO2 in exercises of highly trained basketball players has been taken.

The aim of this study was to investigate changes in physical and physiological responses to different modes of RSE by measuring speed, total time (TT) (sum of sprints), fatigue index (FI), HR, SmO2, total haemoglobin content (THb), and BLa.

**Methods**

**Participants**

Twelve highly trained male basketball players (age 21 ± 1.9 y, body mass 86.2 ± 5.8 kg, body height 189.6 ± 6.8 cm, BMI 23.9 ± 1.3 kg·m⁻², standing reach 247.8 ± 9.6 cm) voluntarily participated in this study. All participants competed regularly at an elite level and had 12 ± 1.9 years of basketball training experience with ~10 h of training per week. Prior to testing, all players were fit, free from injury and provided written informed consent to participate in the study. Tests were completed on a certified indoor wooden basketball flooring with players wearing basketball shoes and sportswear. To eliminate any influence of circadian rhythm, each participant completed all trials at the same time of the day (1 - 3 pm) in ambient conditions of 20 ± 0.5°C of temperature and 60 ± 2% of relative humidity. Ethical approval conformed to the recommendations of the Declaration of Helsinki and was provided by the local Institutional Research Ethics Committee.

**Experimental procedure design**

We used a single-group repeated-measures study design in which the RSE mode was the independent variable, whereas speed, TT, FI, SmO2, THb, BLa, HR and FI between sets of exercise were dependent variables. Participants were familiarised with the RSE1 and RSE2 experimental procedure. The volume of work performed during both exercises was 900 m with the same exercise-to-rest ratio of 1:5, but with a different distribution of the exercise to rest ratio – RSE1 being 6 s of sprint to 30 s of rest and RSE2 being 3 s of sprint to 15 s of rest. Participants performed two randomized exercise sessions with 7 days between each testing day in which all players completed three trials of maximal sprints with a 5 min rest interval between bouts. RSE1 consisted of ten 30 m shuttle sprints (15 m + 15 m) with a change in direction of 180°, interspersed with 30 s of passive recovery (walking back to the starting line and waiting for the next sprint). Participants started from the starting line, sprinted...
in-line for 15 m, touched a line on the floor with the outside foot and then ran back to the starting line as fast as possible. To eliminate discrepancies in fatigue between the participants’ legs, they were asked to alternate the leg they started each sprint.

RSE2 consisted of twenty 15 m shuttle sprints interspersed with 15 s of passive recovery (walking back to the finish line and waiting for the next sprint). All exercise sessions started with a 10 min warm up of low-intensity running (~8 km · h⁻¹) and 5 min of standardised dynamic stretching.

The time for each single shuttle sprint was recorded using two sets of photocell gates (Brower Timing System, Salt Lake City, UT, USA; accuracy of 0.01 s) placed at a height of 50 cm at the start and finish lines.

The FI was determined by taking the percentage difference between maximal and minimal speed performance during the RSE:

\[
FI (\%) = 100 - \frac{\text{SpeedMin} \times 100}{\text{SpeedMax}}
\]

All participants were asked to refrain from vigorous exercise 24 hours prior to testing. No additional strength, power, or plyometric training was performed during the testing period. Caffeine ingestion was forbidden before testing.

**Near-infrared spectroscopy**

NIRS measurements were made using the Moxy monitor (Moxy, Fortiori Design LLC, Minnesota, USA). The Moxy device is based on sequentially sending light waves (630 – 850 nm) from four light emitting diodes into the tissue beneath it and recording the amount of returned scattered light at two detectors positioned 12.5 and 25 mm from the light source. The penetration depth of the light received at each detector is half the distance between the light source and the detector. The scattered light is processed by an algorithm, which combines a tissue light propagation model and the Beer–Lambert law to determine the amount of light absorbed at wavelengths pertaining to oxygenated and deoxygenated Hb. This allows calculation of THb present beneath the device, as well as the percentage of Hb containing O₂ (SmO₂). Because light passing into micro-vessels with a diameter greater than 1 mm is expected to be completely absorbed, it is assumed that the majority of reflected light comes from the capillaries, and thus the measurements obtained reflect the relative supply of O₂ to the muscle versus its uptake (Fortiori Design LLC, 2015).

The Moxy was positioned on the participant’s dominant leg, on the *vastus lateralis*, halfway between the greater trochanter and lateral epicondyle of the femur. Prior to placement, this area was trimmed with an electric razor (if necessary) and cleaned with alcohol swabs. The device was secured with a light shield and athletic tape to block ambient near-infra red light from interfering with the detectors, and its exact position was recorded and replicated for the second RSE session. After resting in a seated position for five minutes, measures for SmO₂ and THb were recorded. Minimum local oxygen saturation (SmO₂min) was defined as the lowest value of SmO₂min registered during the sprints and average local oxygen saturation (SmO₂avg) value was calculated during the sprints.

**Blood Lactate Concentration Assessment**

BLa concentration (mmol·L⁻¹), as a proxy for metabolic-anaerobic demand, was determined 3 minutes after the end of the RSE1 and RSE2 sessions (Hirvonen et al., 1987). Blood lactate samples were taken from the participants’ fingertip and immediately analysed with a validated lactate analyser (Lactate Pro; Arkray, Tokyo, Japan).

**HR measures**

Participants were equipped with a telemetric HR monitor (Polar RS800 CX, Polar Electro Oy, Finland). The HR was then continuously registered throughout the RSE and during the 5 min rest interval between trials. Raw HR data were automatically filtered using a moderate filter and all irregular heartbeats were replaced with interpolated adjacent R-R interval values using the Polar Software (Pro Trainer 5, Polar Electro, Finland). The maximum heart rate (HRmax) was defined as the highest value of the HR registered during the sprints and average heart rate (HRavg) value was calculated during the sprints.

**Statistical analysis**

Descriptive statistics were used to compute means and standard deviations (SD). Statistical analysis was performed with SPSS 23.0 (SPSS Inc. Chicago, IL, USA). The normal distribution of the variables was assessed for all groups under each condition using the Shapiro–Wilk test and visual inspection of Q–Q plots. Data
were subsequently assessed using parametric statistics, with the maximum priority level being set at 0.05. The homogeneity of variance was verified by the Bartlett’s test. The analysis was performed using general linear model for repeated measures analysis of variance (ANOVA) with a compound symmetry working covariance matrix on the following dependent variables: speed, TT, FI, SmO₂, HR, THb, FI, BLa. The same model was used to analyse the effect of each work interval on the exercise mode among the RSE1 and RSE2. The level of significance was set at \( p < 0.05 \).

**Results**

**Performance variables**

All performance variables for both RSE1 and RSE2 are shown in Table 1. A comparison of speed of RSE1 and RSE2 revealed a significant main effect on variables within different work modes (\( F = 189.159, p < 0.001 \)). Repeated measures analysis within each work interval showed a significant decrease of speed in both (RSE1 and RSE2) exercises (\( F = 6.897, p < 0.05 \) and \( F = 5.985, p < 0.05 \)), respectively. The work mode revealed a significant effect on TT between RSE1 and RSE2 (\( F = 176.732, p < 0.001 \)). During each bout, TT increased significantly (RSE1 \( F = 12.505, p < 0.05 \); RSE2 \( F = 5.785, p < 0.05 \)). The study showed that the FI changed significantly (\( F = 18.012; p < 0.01 \)) within RSE1 and RSE2.

**Physiological variables**

Fluctuations in HR and SmO₂ variables during the exercise and rest periods are shown in Figures 1 and 2. As RSE1 and RSE2 exercise intensity increased, there was an increase in the HR and a decline in SmO₂. Data detailing physiological variables are presented in Table 2. Our study showed that during each work interval the HR\(_{max}\) increased significantly (RSE1 \( F = 6.017, p < 0.05 \); RSE2 \( F = 17.959, p < 0.05 \), but with no significant difference between RSE1 and RSE2. The HR\(_{avg}\) in both RSE1 and RSE2 increased significantly (RSE1 \( F = 16.817, p < 0.001 \); RSE2 \( F = 63.910, p < 0.001 \), but with no significant difference between the two modes of exercise (\( F = 0.013, p > 0.05 \)). No significant differences were found in SmO₂\(_{min}\) within work intervals and between RSE1 and RSE2 (\( F = 0.276, p > 0.05 \)). There was also no significant difference in SmO₂\(_{avg}\) within work intervals and between RSE1 and RSE2 (\( F = 0.113, p > 0.05 \). THb showed little variation throughout each test and was not significantly associated with changes in exercise mode (\( F = 0.426, p > 0.05 \)).

**Table 1**

*Results of physical variables analysed during different mode of repeated sprint exercises (RSE1 and RSE2)*

| Variables | 1 bout | 2 bout | 3 bout | F | RSE1 | RSE2 | RSE1-RSE2 |
|-----------|--------|--------|--------|---|------|------|-----------|
| Speed (m·s\(^{-1}\)) | 5.14 ± 0.14 | 5.07 ± 0.17 | 5.01 ± 0.20 | 6.897* | 5.63 ± 0.17 | 5.61 ± 0.15 | 0.17 | 0.17 | 5.56 ± 0.17 | 5.985* | 189.159* |
| TT (s)    | 58.45 ± 1.63 | 59.25 ± 2.03 | 60.02 ± 2.41 | 12.505* | 53.37 ± 1.64 | 53.58 ± 1.45 | 1.63 | 1.63 | 54.04 ± 1.63 | 5.785* | 176.732* |
| FI (%)    | 6.14 ± 2.80 | 7.59 ± 2.67 | 7.09 ± 3.45 | 12.222 | 10.92 ± 3.86 | 11.58 ± 2.65 | 3.12 | 3.12 | 10.75 ± 3.65 | 0.368* | 18.012* |

*Notes: The value expressed as mean and standard deviation (SD) in both repeated sprint exercises (RSE1) and (RSE2). *Significant differences (p < 0.05).*
Table 2
Results of physiological variables analysed during different mode of repeated sprint exercises (RSE1 and RSE2)

| Variables | 1 bout | 2 bout | 3 bout | F | 1 bout | 2 bout | 3 bout | F | F |
|-----------|--------|--------|--------|---|--------|--------|--------|---|---|
| SmO2min (%) | 25.66 ± 12.44 | 19.66 ± 13.03 | 20.83 ± 16.19 | 3.230 | 26.08 ± 22.48 | 23.91 ± 22.87 | 22.00 ± 23.91 | 0.601 | 0.276 |
| SmO2avg (%) | 40.83 ± 12.95 | 37.77 ± 13.07 | 40.30 ± 15.71 | 0.981 | 37.01 ± 21.83 | 36.33 ± 21.42 | 40.16 ± 21.67 | 1.466 | 0.113 |
| THb (dL⁻¹) | 12.36 ± 0.52 | 12.43 ± 0.52 | 12.36 ± 0.49 | 1.191 | 12.41 ± 0.59 | 12.39 ± 0.59 | 12.33 ± 0.60 | 1.611 | 0.426 |
| HRmax (bpm) | 174.58 ± 7.61 | 178.25 ± 5.48 | 181.83 ± 10.17 | 6.017 | 174.08 ± 8.77 | 177.75 ± 8.51 | 179.33 ± 7.35 | 0.819 | * |
| HRavg (bpm) | 162.80 ± 9.14 | 169.06 ± 6.65 | 169.46 ± 6.54 | 8.53 ± 3.44 | 161.32 ± 8.95 | 169.67 ± 8.18 | 170.84 ± 8.18 | 0.013 | * |
| BLa (mmol·L⁻¹) | 13.02 ± 2.28 | - | - | - | 8.53 ± 3.44 | - | - | - | 34.070 | * |

Notes: The value expressed as mean and standard deviation (SD) in both repeated sprint exercises (RSE1) and (RSE2). *Significant differences (p < 0.05)

Figure 1
Representative local oxygenation (SmO2) data during repeated sprint exercises. The open cube and closed triangle indicate RSE1 and RSE2 values in every 20-s window, respectively. The B and R denote active bouts and resting periods, respectively.
Discussion

The first goal of this study was to assess performance differences in RSE1 (one change of direction during the sprint) with respect to RSE2 (straight sprints). The speed achieved during both exercise modes significantly decreased with subsequent sprints. The RSE1 average sprint speed was by 8.7 – 9.9% lower than RSE2. The TT difference between exercises varied from 5.08 to 5.98 s on average.

Given these differences, it could be suggested that RSE1 and RSE2 utilise different aspects of motor function. Brughelli et al. (2008) highlighted that straight sprints (in-line) and changes of direction had mostly separate motor qualities because the shared variance was ≤53%. Examining findings reported by Brughelli et al. (2008), most correlations between change of direction and straight running speed would be described as moderate (r = 0.3-0.5). Changes of direction played a key role, and it was considered as the interplay of a number of physical and neuromuscular components (Sheppard and Young, 2006).

The fatigue results show that a significant interaction exists between each exercise mode. The FI during both exercises did not significantly decrease. In shorter sprints of RSE2, recovery time between sprints was also shorter. However, the FI of RSE2 was 3.6 – 4.8% higher than of RSA1. This overall finding supports previous research reporting that performance and fatigue during repeated sprints are strongly influenced by the recovery duration (Attene et al., 2014). Glaister (2005) claims that fatigue can often be masked by a potentiation effect. This effect is apparent in a number of investigations, the mechanisms of which remain largely unresolved (Hamilton et al., 1991; MacIntosh et al., 2002).

Our research into the physiological demands of RSE indicates that these workouts place considerable demand on both aerobic and anaerobic pathways. The average physiological response to repeated sprint work is reported to be within intensities of 37–40% maximum SmO2avg and HRmean of 92 – 95% of maximum. Different modes of RSE did not show significant difference.
in the aerobic muscle metabolism. Meanwhile, the
BLa content after RSE1 was 13.02 mmol·L⁻¹, and
after RSE2 significantly lower at 8.53 mmol·L⁻¹,
which shows active anaerobic metabolism.
Hamilton et al. (1991) found strong correlations
between peak blood lactate and peak speed (r =
0.90, *p < 0.01) and between peak blood lactate and
peak power fatigue (r = 0.92, *p < 0.01) during 10 ×
6-s all-out sprints with 30 s recovery periods
implying a high glycolytic rate during this activity
which has been confirmed by the high lactate
concentration observed in another study using
similar protocols (Hamilton et al., 1991).

The indication that performance during
repeated sprints is regulated predominantly by
PCR availability provides the most likely
explanation for the significant differences between
the two exercise modes in terms of BLa
accumulation. Indeed, higher RSE1 BLa may be
associated with lower PCR during the exercise
protocol with longer sprints and one change of
direction, as accumulation of metabolites in the
process of ATP-Cr splitting (i.e., pyruvate,
adenosine diphosphate, and adenosine
monophosphate) is suggested to be a stimulus for
anaerobic glycolysis (Crowther et al., 2002).

However, previous investigation on the
physiological response to RSA have reported an
evident inhibition of glycolysis over multiple
sprints (Glaister et al., 2008). It should be noted that
BLa concentration is only a reflection of the
dynamic balance between its production and
clearance, and only one measurement at the third
minute after the end of the test may not truly reflect
the BLa level given its normal variability (Glaister
et al., 2008).

Recordings of muscle oxygenation during
RSE1 and RSE2 are presented in Figure 1. A
decrease in muscle oxygenation during exercise
would reflect an increase in the degree of muscle
oxygen diffusion as well as muscle oxygenation
would reflect the balance between muscle oxygen
utilization and supply (Shibuya and Tanaka, 2003).
Our study showed that the different modes of
workouts did not have a significant effect on
muscle oxygenation. The moderate inverse
correlation between SmO₂ and VO₂ (r = −0.73) is in
accordance with Born et al. (2016) who found that
changes in SmO₂ in the vastus lateralis of elite
runners competing in an undulating trail running
race closely corresponded to changes in VO₂.

Shibuya and Tanaka (2003) concluded that one of
the limiting factors of VO₂max was the muscle
oxygen diffusion capacity, and SmO₂ during
exercise could be one of the indexes of muscle
oxygen diffusion capacity. Since SmO₂ is a measure
of the mean localised muscle capillary content,
greater O₂ muscle uptake means the O₂ content of
the capillaries perfusing the muscle will decrease,
as this includes the inflow of O₂ as well as the
outflow of CO₂ (Bhambhani, 2004). In addition, the
greater rate of mechanical work requiring greater
VO₂ results in an increased concentration of
intramuscular adenine diphosphate, which signals
a need for more oxidative ATP production and
further promotes O₂ diffusion into the muscle
(Bassett and Howley, 2000).

Very small variation was found in THb
values throughout exercises, despite significant
changes in all other measured variables. It is likely
that our participants had a sufficient supply of
oxygenated Hb to the muscles throughout the test,
and were not limited by a lack of O₂ availability,
even at the maximum intensities.

The HR significantly increased during
both RSE modes. Dynamics of the HR during
particular exercises is presented in Figure 2. After
repeated sprints, the blunted responsiveness of the
HR could be related to a higher anaerobic
contribution during exercise and the elevation of
adrenergic factors and local metabolites during
recovery (Buchheit et al., 2007). Along this line of
reasoning, those individuals showing distinct
aerobic and anaerobic contributions to a given
exercise load would therefore also display
disparate post-exercise HR responses (Del Roso et
al., 2017). Daanen at al. (2012) claim that HR
discriminates between the mode and intensities of
exercise. Our study cannot confirm this statement
because there was no significant difference in HR
dynamics between the different modes of sprint
exercises. HR recovery in healthy individuals is
governed by the autonomic nervous system and it
is characterised by parasympathetic reactivation
and sympathetic withdrawal (Borresen and
Lambert, 2008; Daanen et al., 2012). It was also
argued that as the autonomic nervous system
interacts with other physiological systems,
monitoring of the HR recovery as a reflection of the
autonomic nervous system in response to an
exercise stimulus may reflect body’s ability to
respond to the stress of such a stimulus (Borresen
and Lambert, 2007). Our study of HR response of recovery kinetics in basketball players after different modes of exercise does not support this allegation.

**Conclusion**

In conclusion we may state that different modes of repeated sprint exercises cause a different physical response and metabolic demands in highly trained basketball players. Longer sprints with directional changes place a higher demand on the anaerobic glycolytic system compared to straight and more frequent sprint exercises. However, basketball player’s fatigue is more noticeable in shorter and more frequent sprints. The mechanisms of fatigue and the factors that regulate the same require further investigation. HR responses and local use of O₂ show a similar activity of aerobic reactions through both types of exercise. During the sprints basketball players’ SmO₂ falls to 40% and recovers to the level of about 80% during the passive recovery periods without showing significant differences between exercises. This proves that both workouts can similarly stimulate aerobic metabolism. Therefore, the concept of the distance covered during the match or exercise, the rest interval and the work ratio, becomes incomplete in describing physical activity because the specificity of physical activity can lead to different physiological responses. A greater understanding of the physiological response to repeated sprint exercises is likely to help athletes and coaches improve basketball performance.

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Corresponding author:

Prof. dr. Rū tenis Paulauskas
Vytautas Magnus University, Education Academy.
T. Ševčenkos g. 31, 03111 Vilnius, tel. (8 5) 279 02 81, Lithuania.
Phone number: +37069893079
E-mail: rutenis.paulauskas@vdu.lt