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Assessment of repeated vertical jump for anaerobic exercise performance

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Abstract
Background: Lower body power and strength are important in many sports such as volleyball and basketball. One way to assess explosive lower body power and strength is to measure maximal height during vertical jump, which is decreased with muscular fatigue. In the current investigation, we developed and tested a new protocol for anaerobic vertical jump performance with a frequency of 12 jumps/min. To do this, we assessed three rounds of 30 consecutive vertical jump performance with 5-minute resting period.
Methods: Twelve young, healthy, and recreationally active males (25.4 ± 1.4 yrs., 79.2 ± 3.2 kg, 178.2 ± 1.7 cm) participated in the current study. Subject performed a total of 3 sets of 30 consecutive maximal vertical jumps with 5 min recovery period following each set. After the first (ROUND 1) and second set (ROUND 2) of vertical jump exercise, subjects rested in the chair for 5 min. Following the last set of vertical jump exercise (ROUND 3), subjects rested for 30 min.
Results: In all rounds, vertical jump height steadily decreased during 30 consecutive jumps (p<0.001). As expected, jump performance during Round 2 and 3 was lower relative to Round 1. Also, vertical jump performance during Round 2 and 3 decreased earlier when compared with that during Round 1. Exercise intensity of the repeated vertical jump in the current study is around 80-85% of maximal exercise.
Conclusion: With these analyses, future studies may develop and validate various exercise training to improve anaerobic exercise capacity or recovery strategies to minimize fatigue during lower limb exercise.

Keywords: Anaerobic exercise, performance, vertical jump, fatigue

1. Introduction
The assessment of exercise capacity is critical for athletes as well as non-athletes to optimize exercise training program and recovery strategy. To date, researchers have developed many methods for assessing aerobic and anaerobic exercise performance [1-3]. While the assessment of aerobic capacity has been extensively explored [4], the evaluation of anaerobic power performance still remains limited due to its complexity.
Lower body power and strength are important in many sports such as volleyball and basketball. One way to assess explosive lower body power and strength is to measure maximal height during vertical jump, also known as the Sargent jump, which is decreased with muscular fatigue [5, 6]. Thus, many researchers have utilized this approach to evaluate an individual's performance level in response to various training modes or other recovery interventions [5, 6]. Bosco *et al*. developed a anaerobic test based on repeated vertical jumps [7]. However, Bosco's test used a frequency of 60 jumps in one minute, which may not reflect jump performance in real sports situation. Tkac *et al*. also developed repeated vertical jump protocol for 10 seconds as an assessment of explosive anaerobic power [8]. Their protocol may be appropriate for explosive anaerobic performance such as 100m sprint, however, this protocol would not be applied in other sports such as volleyball and basketball, which show lower frequency of jumps. For example, studies showed that basketball or volleyball players jump on average 60-100 jumping movements during a match [9].
In the current investigation, we developed and tested a new protocol for anaerobic vertical jump performance with lower frequency (12 jumps/min) when compared with other previous

studies. To do this, we assessed three rounds of 30 consecutive vertical jump performance with 5-minute resting period. We also analyzed as to how jump performance changes over time (i.e., fatigue pattern) as well as changes in heart rate and blood lactate level as a fatigue index.

2. Materials and methods

2.1 Ethical Approval

The Institutional Review Board (IRB) at Jeonbuk National University approved all study procedures used in the current experiment (IRB File #: JBNU 2019-07-014-003). Participants were given a verbal description of all procedures and informed of the purpose and risks involved in the study. Written consent was obtained before the study began. The study conformed to the provisions of the Declaration of Helsinki.

2.2 Subjects and Experimental Protocol

Twelve young, healthy, and recreationally active males (25.4 ± 1.4 yrs., 79.2 ± 3.2 kg, 178.2 ± 1.7 cm) participated in the current study. Participants were instructed to maintain their regular diet during the participation period and were asked to refrain from strenuous exercise, alcohol, and caffeine consumption during the 24 hours preceding the visit. During the experiment, air cushioning shoes were not allowed due to its effects on jump performance.

A schematic of the experimental protocol is presented in Figure 1. Subjects visited the laboratory a total of 2 times, consisting of one familiarization visit and one test visits. The familiarization visit was for minimizing potential learning effects. During the first visit, participants were informed of the overall experimental protocol, potential risks, and purpose of the study. After completion of a written consent form, participants were familiarized with repeated vertical jump exercise. Body mass (kg) and height (cm) were also measured during this session.

The following test visit were completed with at least a 72-hour separation. Participants had their meals at least 3 hours before the visit to prevent stomach upset in response to an exhaustive exercise. Food and water were not given during the entire procedure. Once arrived, baseline heart rate (Polar, USA) and blood lactate (AccuTrend Plus, Roche, Germany) were measured after 10 min resting period, which was followed by a light warm-up exercise with a cycle ergometer (Monark 894E, Vansbro, Sweden) with a speed of 100 RPM for 5 min without resistance. Then, subject performed a total of 3 sets of 30 consecutive maximal vertical jumps with 5 min recovery period following each set. After the first (ROUND 1) and second set (ROUND 2) of vertical jump exercise, subjects rested in the chair for 5 min. Following the last set of vertical jump exercise (ROUND 3), subjects rested for 30 min. Time points for heart rate and lactate measurements were shown in Figure 1.

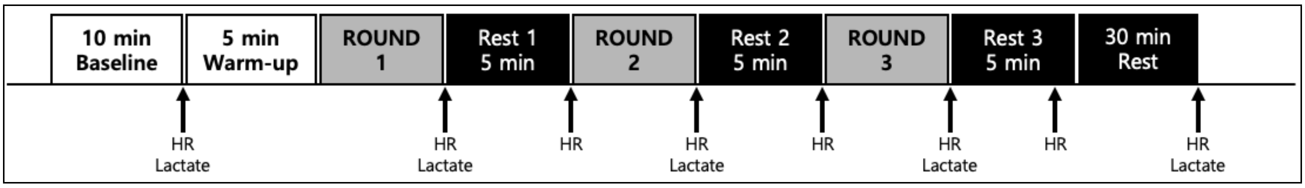

Fig 1: Schematic representation of the experimental protocol. HR, heart rate; Lactate, blood lactate measurement

2.3 Vertical Jump

Duration of jump was measured as an index of jump height by a digital vertical jump equipment (TKK-5414, TAKEI, Japan). During each set, subjects jumped with instruction of a metronome sound with a cadence of 12 jumps/min, such that total exercise time of each set took 150 sec. To minimize effects of arm swing during the jump, both arms were crossed, and hands were placed on shoulders. Subjects were not allowed to see their own jump height record that appeared on the screen of the equipment to minimize a feedback effect.

2.4 Statistical Analysis

Data are expressed as the mean ± SE. One-way repeated measures analysis of variance (one-way RM ANOVA) was used to analyze jump performance, lactate, and heart rate (Round x Repetition), which was followed by Tukey post hoc analysis. Significance was set at $p<0.05$ (Prism 8.3, GraphPad).

3. Results

3.1 Vertical jump performance

In all rounds, vertical jump height steadily decreased during 30 consecutive jumps (Figure 2, main effect of repetition; $p<0.001$). As expected, jump performance during Round 2 and 3 was lower relative to Round 1 (Main effect of round; $p<0.001$), such that there was a significant interaction between Round and Repetition; $p<0.05$).

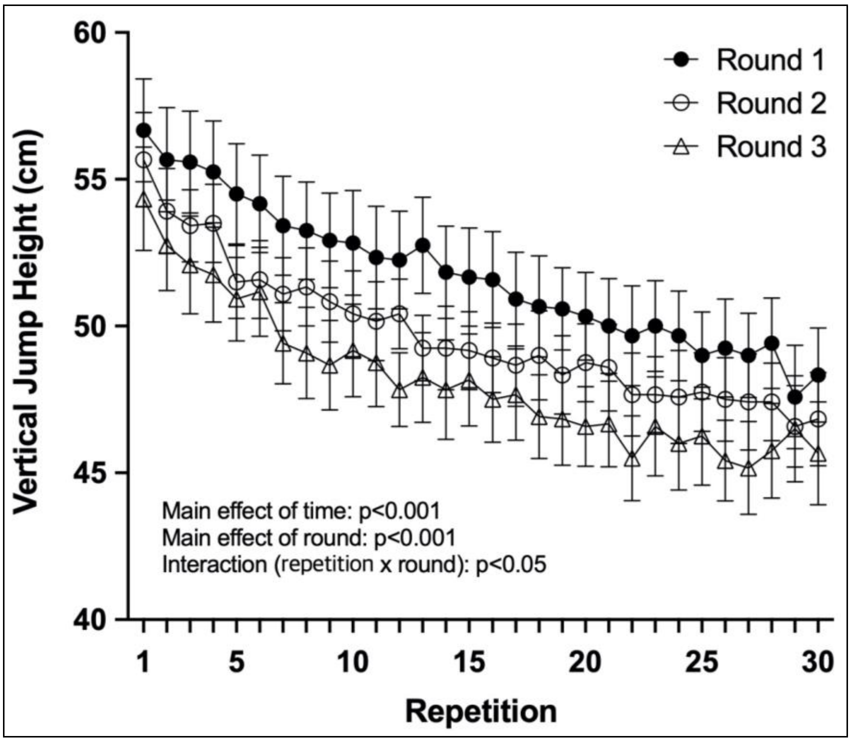

Fig 2: Vertical jump height. Data. Values represent mean ± SE.

Furthermore, we compared cumulative height of each Round (Figure 3A). Cumulative height of Round 2 was decreased when compared with that of Round 1 (Figure 3A, Round 1 1551 ± 47 vs. Round 2 1490 ± 39 cm; $p<0.05$), which was further decreased in Round 3 (Figure 3A, Round 2 1490 ± 39 vs. 1445 ± 45, $p<0.05$).

To analyze fatigue patterns during repeated vertical jump, jump height averaged for every 5 jumps was compared with the first jump of each round (Figure 3B). Interestingly, jump performance during Round 2 and 3 decreased earlier when compared with that during Round 1 (Figure 3B). However, there were no differences between Round 2 and 3.

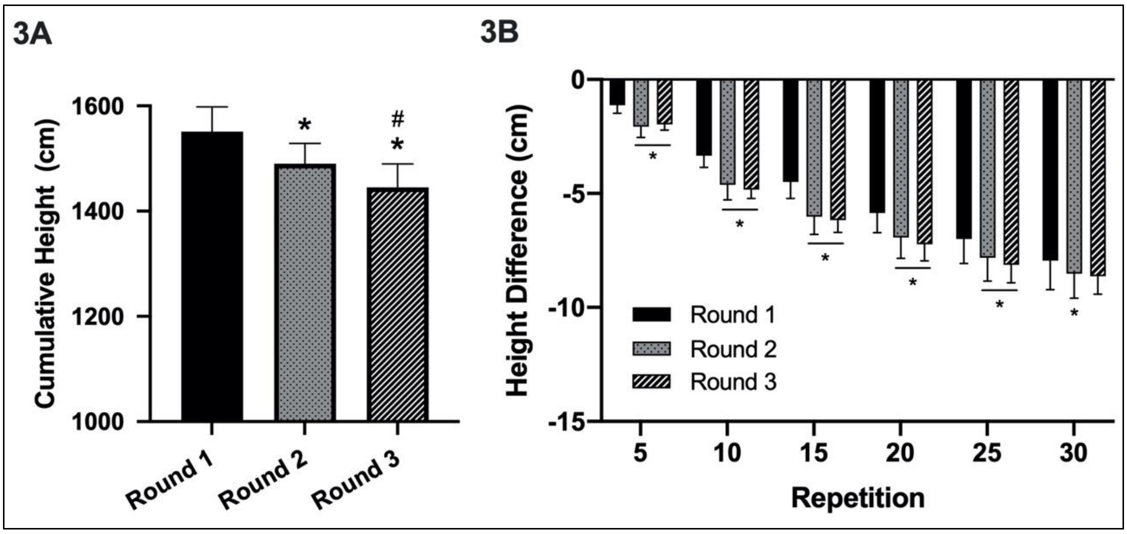

Fig 3: Cumulative height and height difference. Cumulative height from each round is shown in 3A. Changes in height during 30 repeated vertical jumps are shown in 3B. *$p<0.05$ vs. Round 1. Values represent mean ± SE.

3.2 Blood lactate and heart rate

Blood lactate level increased after Round 1, 2, and 3 relative to baseline (Figure 4A, Baseline 4.4 ± 0.5 vs. Round 1 10.0 ± 1.2 vs. Round 2 10.8 ± 1.6 vs. Round 3 12.1 ± 1.5 mmol/L; $p<0.01$). 30 min post Round 3, Lactate level returned to the baseline level (Baseline 4.4 ± 0.5 vs. After 30 min 5.6 ± 0.6 mmol/L, $p>0.05$).

As expected, heart rate (HR) dramatically elevated after Round 1 and decreased after the 5 min recovery (Figure 4B, Baseline 73 ± 2 vs. Round 1 168 ± 4 vs. Rest 1 96 ± 4.0 beats/min; $p<0.01$). Similar patterns in HR were seen in Round 2 and 3 (Round 2 174 ± 4.0 vs. Rest 2 103 ± 5 vs. Round 3 176 ± 4 vs. Rest 3 105 ± 5 beats/min; $p<0.01$). Further decrease in HR was seen 30 min following Round 3 (Rest 3 105 ± 5 vs. 30-min rest 89 ± 4 beats/min; $p<0.05$), which was still higher than HR during baseline (Baseline 73 ± 2 vs. 89 ± 4 beats/min; $p<0.05$).

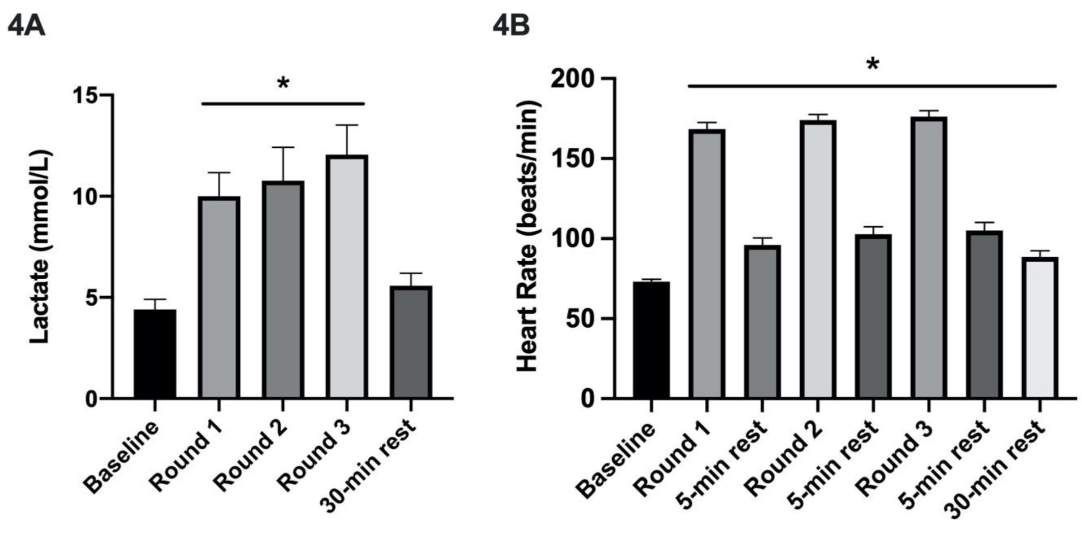

Fig 4: Changes in blood lactate and heart rate. *$p<0.05$ vs. baseline. Values represent mean ± SE.

4. Discussion

In the current study, we show that a modified vertical jump protocol is a reliable test to evaluate one's explosive anaerobic jump performance. Vertical jump performance decreased over 30 repetitions with a frequency of 15 jumps/min. Also jump performance in subsequent rounds displays different patterns, such that earlier decrease in jump height during Round 2 and 3 when compared with performance during Round 1 (Figure 2).

In the current, we measured vertical jump height during 30 jumps, and analyzed cumulative height in each round and height decline during 30 jumps. Cumulative height shows total work produced in each round, which declined progressively over time (Figure 3A). Also, the earlier decline in vertical jump performance during Round 2 and 3 indicates that fatigue patterns are different from that during Round 1 (Figure 3B). With these analyses, future studies may develop and validate various exercise training to improve anaerobic exercise capacity or recovery strategies to minimize fatigue during lower limb exercise.

We also assessed changes in blood lactate level and heart rate before and after repeated vertical jumps as an index of exercise intensity and fatigue. Given the indirect calculation from the heart rate reserve (HRR), exercise intensity of the repeated vertical jump in the current study is around 80-85% of maximal exercise [10] (Figure 4B). Blood lactate level was higher than 10mmol/L right after the repeated vertical jump (Figure 4A), which indicates a high intensity exercise [11]. Together, repeated vertical jump protocol in the current study can be considered as a high intensity exercise.

Assessment of anaerobic power is complicated due to involved muscle group, shortening speed required for specific movement, duration of exercise, and energy substrate (i.e., phosphagen and glycolytic pathways), etc. [8] To measure the anaerobic capacity, Wingate institution developed the Wingate anaerobic test (WAnT) using cycle ergometer [12]. Wingate test (WAnT) is a most widely utilized method for assessment of anaerobic exercise capacity, which determines the maximum power in watts, speed in rpm, and fatigue. While WAnT can be an appropriate measurement mode for cycling and running exercise based on the fact that WAnT requires lower body anaerobic power and muscles involved in cycling muscle movement, explosive jump performance could not be fully evaluated by WAnT. In this regard Sands *et al.* compared between WAnT and Bosco test, which lasts 60 seconds with a frequency of 60 jumps/min. They showed heterogenous aspects of anaerobic capacity and determined that jump test is more appropriate mode for assessing athletes who are familiarized with jump exercise [13]. Cular *et al*. also showed that repeated vertical jump test is superior to WAnT because repeated jump test produces a lower VO_2 due to different exercise type (circular movement in WAnT vs. continuous jump with free joint [14].

Recent study by Sales *et al*. show that peak power measured by vertical jump test is strongly associated to running-based anaerobic sprint test, such that vertical jump test can be used as an alternative to sprint test [15, 16]. In this regard, findings in the current study suggest that repeated vertical jump performance and fatigue pattern could be utilized as an alternative to those of running-based anaerobic sprint test. Further study is necessary to investigate relationship between repeated vertical jump test and sprint test as a method of anaerobic power and fatigue pattern.

5. Conclusion

In the current study, we show that a modified vertical jump protocol with a frequency of 12 jumps/min is a reliable test to evaluate one's explosive anaerobic jump performance. With these analyses, future studies may develop and validate various exercise training to improve anaerobic exercise capacity or recovery strategies to minimize fatigue during lower limb exercise.

6. Conflict of interest

None declared.

7. Funding Sources

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8. Acknowledgments

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