The effects of dynamic stretching performed before and between the sets of exercises on vertical jump performance

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ABSTRACT

The purpose of this study was to investigate the effects of dynamic stretching (DS) performed before and between the sets of exercises on vertical jump performance. Twelve healthy adult males performed DS on their lower limb muscles, with 10 repetitions on each side before and between four sets of three repetitions of vertical jumps. Vertical jump height was measured. Additionally, the percent change in jump height for each set was determined based on the baseline score from set 1. Heart rate was also measured at rest, before exercise, and before each set of vertical jumps. Vertical jump height was significantly higher in the latter half of the sets ($p < .05$) compared to the condition in which DS was only performed before exercise and to the control condition in which the participants were refrained from performing DS throughout. In addition, when DS was only performed before exercise, vertical jump height was significantly lower in set 4 compared to set 1 ($p = .001$). These findings suggest that DS performed between sets, in addition to performing before the exercise, produces a higher power output in vertical jump performance in the latter half of multiple sets.
Keywords: Performance analysis, Inter-set stretching, Power, Jump height, Plyometrics, Athletic performance.

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INTRODUCTION

Dynamic stretching (DS) is widely used as part of the warm-up phases of competition and resistance training. DS is a method to improve dynamic flexibility related to actual sports motion by simulating the motion (Yamaguchi et al., 2007). DS which involve controlled movement through the active range of motion for each joint (Fletcher, 2010) is currently replacing static stretching in warm-up (Behm & Chaouachi, 2011). It has been reported that DS performed before exercise increases heart late (Fletcher, 2010; Fletcher & Monte-Colombo, 2010a) and core temperature (Fletcher & Jones, 2004; Fletcher & Monte-Colombo, 2010b), induces post-activation potentiation in the stretched muscle caused by voluntary contractions of the antagonist (Hough et al., 2009; Torres et al., 2008), and increases activation of motor units (Fletcher, 2010; Herda et al., 2008). Previous studies have shown that such DS associated factors improve vertical jump (Kurt et al., 2023; Meerits et al., 2014; Smith et al., 2018) and sprint (Lopez-Samanes et al., 2021; Malek et al., 2024) performance, and leg extension power (Yamaguchi et al., 2007). However, it has been suggested that the effects of DS before exercise last only about 5 minutes (Kruse et al., 2013; Smith et al., 2018). Smith et al. (2018) investigated the effects of DS, foam rolling, and their combination for the lower muscles on vertical jump height. As a result, the vertical jump height was higher immediately and 5 minutes after DS compared to baseline values (before DS). However, they found that the effect disappeared after 10 minutes.

In training programs that focus on vertical jump performance and leg extension power, it is common to include multiple sets in the program. In fact, in traditional resistance training, multiple sets of force production with rest between sets are more effective than single set of force production in improving muscle strength (Peterson et al., 2005). Additionally, during the training to improve power production, such as plyometrics, it is common to have long rest periods between sets to ensure adequate recovery (Haff & Triplett, 2016). However, considering the duration of the effects of DS mentioned above, in the case of multiple-set program with long rest periods between sets, it is possible that the effects of DS before exercise disappears in the latter half of the sets. It has been shown that rest between sets affects performance on subsequent sets (Kraemer, 1997), therefore, inter-set strategies are considered important. Considering this, in a multiple-set program, implementing DS before exercise as well as between the sets may be effective in sustaining the effects of DS.

The effects of DS between sets (Arazi et al., 2015; Nasiri et al., 2011; Nasiri et al., 2013) are not widely studied. In a study by Arazi et al. (2015), the participants performed 64 seconds of DS for each of the four muscle groups between the sets of bench press or leg press. As a results, no significant difference was found in the number of repetitions for each set compared to a control condition in which the participants were at rest between sets. On the other hand, in a study by Nasiri et al. (2011), the participants performed 50s of DS for four muscle groups between the sets of bench press. As a results, the average number of repetitions in each set significantly increased compared to the control condition in which the participants rested between sets. Previous studies (Arazi et al., 2015; Nasiri et al., 2011; Nasiri et al., 2013) have focused on the effects on muscular endurance using traditional resistance training exercises and have not reached consensus in their findings. Furthermore, these studies did not consider the effects of DS before exercise. Considering the actual coaching situations, verifying the effects of performing DS not only before exercise but also between sets may provide more beneficial recommendations for strength and conditioning professionals in creating training programs. In addition, by verifying whether the effects of DS are sustained by performing DS between sets, as in plyometrics, it may provide useful suggestions for practical inter-set strategies during plyometric exercises. The purpose of this study was to investigate the effects of DS performed before and between sets of exercises on vertical jump performance, one of the popular plyometric exercises.

METHODS

Experimental design

A randomized crossover trial was conducted to investigate the effects of DS performed before and between sets of exercises on vertical jump performance. The trial consisted of one condition per day, and participants participated in the experiment for 3 days at approximately the same time each day to control for the circadian variation. The intervals between these 3 days were 1-2 weeks. Temperature and humidity were recorded on each experimental day (20.8 ± 0.9°C, 45.7 ± 9.6%). The protocol consisted of three conditions: the FULL condition (FULL), in which DS was performed before as well as between the sets of exercises, the PREcondition (PRE), in which DS was only performed before exercise, and the control condition (CON), in which participants remained at rest and did not perform DS before nor between the sets of exercises. The participants rested in a chair for 5 minutes before their resting heart rates were measured (Fletcher & Monte-Colombo, 2010a; Otterstetter et al., 2013). After a 3-minute warm-up run and warm-up jumps, vertical jump measurements were performed in four sets of three repetitions. In addition, heart rate was measured before each set. In FULL, DS was performed on the three lower limb muscle groups before set 1 and during the intervals between sets. In PRE, the same DS as in FULL was performed only before set 1, and the participants were asked to remain in the seated rest position for the subsequent intervals. In CON, participants were asked to rest in a seated position and did not perform any DS throughout the experiment. The time between the warm-up jumps and set 1 (240 seconds) and the rest intervals (240 seconds) were set to be the same for all three conditions.

Participants

Twelve healthy adult males (35.8 ± 8.0 years, 174.1 ± 5.7cm, 74.5 ± 8.4kg) who regularly performed strength training including plyometrics participated in the experiment. The study conformed to the Declaration of Helsinki and was approved by the Ethics Review Committee of the National Institute of Fitness and Sports in Kanoya (23-1-49). All participants were fully informed of the purpose and content of the study as well as the risks associated from participating in the study, and their written informed consent was obtained.

Procedures

Vertical jump

Vertical jump was assessed using the Vertec (West Warwick, RI, USA) vertical jump apparatus. Participants first had their standing reach measured by raising their dominant arm and touching the highest vane possible with their middle finger (Stroiney et al., 2020). The participants were then instructed on the proper form for jumping and were allowed three warm-up jumps. After each treatment, their heart rate was measured. Then, participants performed four sets of three vertical jumps with 240 seconds (Haff & Triplett, 2016) of rest between sets. Participants rested for 10-20 seconds between each jump. The participants jumped from both feet with no step in an attempt to touch the highest vane possible (Holt & Lambourne, 2008). Jump height was calculated by subtracting the standing reach height from the vane height reached by the participant from each jump. The average of three jumps in each set was calculated and used for analysis. The jump height of set 1 was used as the baseline measurement, and the percent change in jump height for each set was also calculated. The intraclass correlation coefficient for vertical jump was 0.977.

Heart rate

Heart rates at rest and before each set were assessed using a Polar H10 HR Monitor (Polar Electro Oy, Finland). The heart rate before each set was recorded within 30 seconds of the completion of DS in FULL (Fletcher & Monte-Colombo, 2010a). In PRE and CON, heart rates were recorded at the same timing as they were recorded during FULL.

Dynamic stretching

The muscle groups that performed DS were gluteus muscles, quadriceps femoris, and hamstrings. These muscle groups are the predominantly active muscle groups in vertical jump (Bobbert & Casius, 2005; Sugisaki et al., 2013). Prior to each routine, the correct stretching techniques were demonstrated and each participant was monitored to ensure that the stretching was conducted properly. Each participant was instructed to intentionally contract the antagonist of the targeted muscles (Holt & Lambourne, 2008) and performed DS once every 2 seconds (Holt & Lambourne, 2008) for 10 times (McMillian et al., 2006) on each side. A digital metronome was used to standardize the timing of each repetition. The total duration of the DS procedure was approximately 2 minutes. Below, is a detailed description of the stretching exercises.

Gluteus muscles: the participant was placed in a drop lunge position, with one leg crossing behind the other leg from an upright position, the foot placed diagonally behind the other leg, and bending the hip joint and knee to lower the body (Figure 1a).

Quadriceps femoris: in the upright position, the participant bent his knee to bring the heel to the buttocks and grabbed the ankle the same time. (Figure 1b).

Hamstrings: in the upright position, the participant kicked a leg forward with a straight knee. (Figure 1c).

Figure 1. Stretching exercises. (a) Gluteus muscles (b) Quadriceps femoris (c) Hamstrings.

Statistical analysis

The sample size was calculated using GPower (version 3.1.9.7, University of Kiel, Germany) with a target effect size (ES) = 0.25, α error probability = 0.05, power (1-β err prob) = 0.80, resulting in an estimated sample of 10 participants per group. A 2-way repeated-measure analysis of variance (ANOVA; set [set 1 or set 2 or set 3 or set 4] × condition [FULL or PRE or CON]) was used to analyse vertical jump height. A 2-way repeated-measure analysis of variance (ANOVA; time [Rest or Before set 1 or Before set 2 or Before set 3 or Before set 4] × condition [FULL or PRE or CON]) was used to analyse heart rate. The assumption of sphericity was confirmed using Mauchly's test. Greenhouse-Geisser epsilon corrections were used when the assumption of sphericity was violated. The effect sizes for main effects and interactions were determined by partial eta squared (η^2_p) values. Partial eta squared (η^2_p) values were classified as small (0.01), moderate (0.06), and large (0.14). Post-hoc analyses of significant main and interaction effects were conducted where appropriate using the Bonferroni correction. The effect sizes (ES) were determined for pairwise comparison using Cohen's *d*. The ES were defined as small (d = 0.2-0.5), moderate (d = 0.5-0.8), and large (d > 0.8).

95% confidence intervals (CIs) were calculated. Differences were considered statistically significant at *p* < .05. Statistical analyses were performed using SPSS version 28.0 (IBM SPSS Statistics Inc, Chicago, IL). All results are presented as mean and SD.

RESULTS

Vertical jump

There was a significant 2-way interaction between set and condition for vertical jump height (p = .002, η^2_p = 0.268). Post-hoc testing with Bonferroni-corrected revealed that the jump height in FULL for set 3 was significantly higher than that in PRE (p = .036, d = 0.276), and the jump height in FULL for set 4 was significantly higher than that in PRE (p = .004, d = 0.318) and CON (p = .021, d = 0.233). In PRE, the jump height for set 4 was significantly lower than set 1 (p = .001, d = 0.196) (Table 1).

Table 1. Table 1 Comparison of vertical jump height between conditions.

	Vertical Jump Height (cm)			
	set1 (95%CI)	set2 (95%CI)	set3 (95%CI)	set4 (95%CI)
FULL	56.6±8.4 (51.3-62.0)	56.7±8.5 (51.3-62.1)	57.0±8.6 (51.6-62.5)*	57.0±8.6 (51.6-62.5)** ***
PRE	56.0±7.9 (51.0-61.0)	55.6±8.0 (50.5-60.7)	54.7±8.0 (49.6-59.8)	54.5±7.6 (49.6-59.3)#
CON	55.5±8.6 (50.0-60.9)	55.4±8.3 (50.1-60.6)	54.9±8.6 (49.4-60.3)	55.1±8.4 (49.8-60.4)

*Note. FULL = FULL condition; PRE = PREcondition; CON = control condition. Data are presented as mean ± SD and 95% confidence interval (95% CI). *p < .05 vs PRE, **p < .01 vs PRE, ***p < .05 vs CON, #p < .05 vs set1 at PRE.*

There was a significant 2-way interaction between set and condition for the percent change in jump height from the baseline score (p = .003, η^2_p = 0.253). Post-hoc testing with Bonferroni-corrected revealed that the percent change in FULL for set 3 (p = .009, d = 1.215) and set 4 (p = .002, d = 1.708) were significantly higher than those in PRE. In PRE, the percent change for set 4 was significantly lower (p = .001, d = 2.240) (Figure 2).

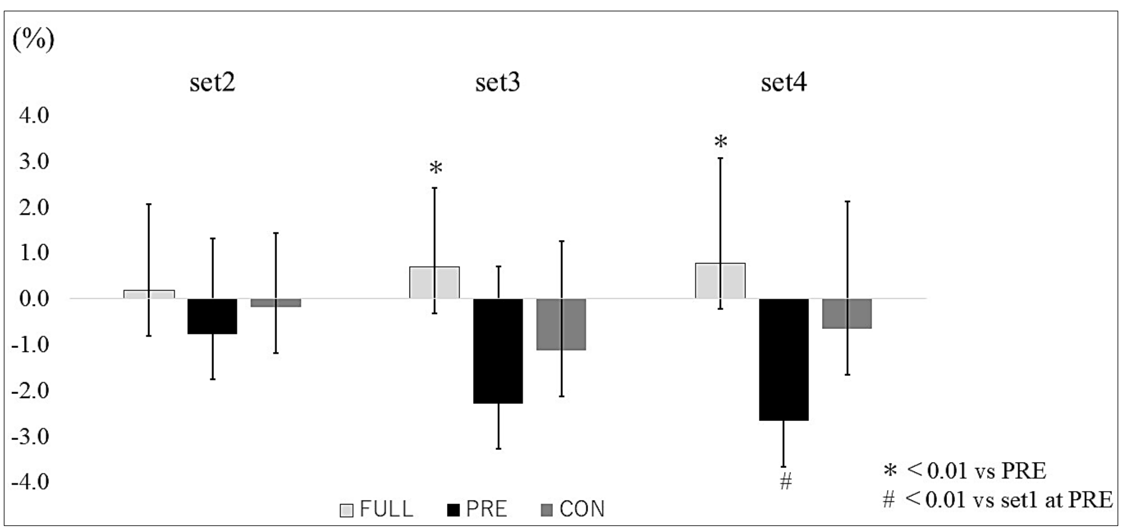

Figure 2. Average percentage change in vertical jump height from set 1.

Heart rate

There was a significant 2-way interaction between set and condition for heart rate (p < .001, η^2_p = 0.821). Post-hoc testing with Bonferroni-corrected revealed that heart rates in FULL (Before set 1 [p < .001, d =

1.795], Before set 2 [$p < .001$, $d = 2.298$], Before set 3 [$p < .001$, $d = 2.493$], Before set 4 [$p < .001$, $d = 2.603$]) and PRE (Before set 1 [$p < .001$, $d = 1.981$], Before set 2 [$p = .024$, $d = 0.651$], Before set 3 [$p = .012$, $d = 0.646$], Before set 4 [$p = .001$, $d = 0.845$]) were significantly higher than those in CON from Before set 1 to Before set 4, and that heart rates in FULL were significantly higher than those in PRE from Before set 2 to Before set 4 (Before set 2 [$p < .001$, $d = 1.892$], Before set 3 [$p < .001$, $d = 2.070$], Before set 4 [$p < .001$, $d = 2.227$]). Additionally, in FULL, heart rates from Before set 1 to Before set 4 were significantly higher than Rest (Before set 1 [$p < .001$, $d = 3.161$], Before set 2 [$p < .001$, $d = 3.058$], Before set 3 [$p < .001$, $d = 3.089$], Before set 4 [$p < .001$, $d = 3.071$]), and heart rates Before set 3 (Before set 1 [$p = .009$, $d = 0.453$], Before set 2 [$p = .003$, $d = 0.181$]) and Before set 4 (Before set 1 [$p = .009$, $d = 0.493$], Before set 2 [$p = .021$, $d = 0.223$]) were significantly higher than Before set 1 and Before set 2. In PRE, heart rates from Before set 1 to Before set 4 were significantly higher than Rest (Before set 1 [$p < .001$, $d = 2.918$], Before set 2 [$p < .001$, $d = 1.329$], Before set 3 [$p < .001$, $d = 1.168$], Before set 4 [$p = .001$, $d = 1.221$]), and heart rates from Before set 2 to Before set 4 were significantly lower than Before set 1 (Before set 2 [$p < .001$, $d = 2.008$], Before set 3 [$p < .001$, $d = 2.088$], Before set 4 [$p < .001$, $d = 2.307$]). Additionally, in CON, heart rates from Before set 1 to Before set 3 were significantly higher than Rest (Before set 1 [$p < .001$, $d = 1.192$], Before set 2 [$p = .003$, $d = 0.918$], Before set 3 [$p = .006$, $d = 0.824$]) (Table 2).

Table 2. Comparison of heart rate between conditions.

	Heart Rate (bpm)				
	Rest (95%CI)	Before set1 (95%CI)	Before set2 (95%CI)	Before set3 (95%CI)	Before set4 (95%CI)
FULL	71±8.4 (66-77)	112±16.3 (102-123)*†	117±19.4 (105-129)*†**	121±21.0 (107-134)*†**‡§	122±21.6 (108-135)*†**‡§
PRE	74±10.9 (68-81)	115±16.5 (105-126)*†	88±9.6 (82-94)$^{\#\dagger\ddagger}$	87±10.1 (80-93)$^{\#\dagger\ddagger}$	86±7.3 (81-90)$^{\#\dagger\ddagger}$
CON	73±9.4 (67-79)	86±12.6 (78-94)†	82±9.8 (76-88)†	81±9.0 (75-86)†	79±8.0 (74-84)

Note. FULL = FULL condition; PRE = PREcondition; CON = control condition. Data are presented as mean ± SD and 95% confidence interval (95% CI). $^{*}p < .01$ vs CON, $^{**}p < .01$ vs PRE, $^{\#}p < .05$ vs CON, $^{\#\#}p < .01$ vs CON, $^{\dagger}p < .05$ vs Rest, $^{\ddagger}p < .05$ vs Before set1, $^{\S}p < .05$ vs Before set2.

DISCUSSION

The purpose of this study was to investigate the effects of DS performed before and between sets of exercises on vertical jump performance. The results revealed that when the DS was performed before and every interval, the vertical jump performance was higher in the latter half of the sets compared to the condition in which DS was only performed before exercise or to the control condition. Furthermore, when DS was only performed before exercise, the vertical jump performance decreased from the baseline in the latter half of the sets.

Previous studies have shown that performing DS before exercise improves vertical jump performance (Hough et al., 2009; Kurt et al., 2023; Meerits et al., 2014; Smith et al., 2018). In a study by Meerits et al. (2014), the participants performed three sets of 20 seconds of DS on the hamstrings. The results revealed that squat jump height was significantly improved compared to the jump before DS. Hough et al. (2009) also had healthy males perform 15 DS on each of the lower limb muscles. They found that the vertical jump performance after DS was significantly higher than that of a control condition in which the participants remained at rest instead of DS, and a condition in which static stretching was performed. However, it has been suggested that these effects of DS before exercise last only about 5 minutes (Kruse et al., 2013; Smith et al., 2018). In this study, vertical jump performance also decreased in the latter half of sets during the PREcondition in which DS was only performed before the exercise. In set 4 of PRE, where performance decreased, at least 12 minutes had passed since the implementation of DS, and therefore it was considered that the effects of DS had disappeared, as in previous studies (Kruse et al., 2013; Smith et al., 2018). On the other hand, in the FULL condition, in which DS was performed before and between sets of exercise, the vertical jump performance was significantly higher in the latter half of the sets compared to the other conditions. Factors that may have contributed to the effects of DS on subsequent performance improvement include increased heart rate (Fletcher, 2010; Fletcher & Monte-Colombo, 2010a) and core temperature (Fletcher & Jones, 2004; Fletcher & Monte-Colombo, 2010b), post-activation potentiation in the stretched muscle caused by voluntary contractions of the antagonist (Hough et al., 2009; Torres et al., 2008), and increased activation of motor units (Fletcher, 2010; Herda et al., 2008). The increased heart rate caused by DS may affect blood flow and core temperature, which in turn may cause an increase in sensitivity of nerve receptors and speed of nerve impulses, therefore enabling muscle contraction to be more rapid and forceful (Fletcher & Monte-Colombo, 2010a). Previous research has shown that DS performed before exercise increased the heart rate, which in turn improved vertical jump and sprint performance (Fletcher & Monte-Colombo, 2010a). However, this study only investigated performance on a single set. In our study, multiple sets of force production were performed. In the PREcondition, in which DS was only performed before exercise, the heart rate and the vertical jump performance significantly decreased in the latter half of the sets. On the other hand, in the FULL condition, the heart rate before each vertical jump was maintained at a high value even in the latter half of the sets. In addition, the subsequent vertical jump performance was also higher than other conditions. In other words, maintaining a high heart rate was thought to result in high vertical jump performance, and therefore it was suggested that changes in heart rate may be related to the effect of DS between sets on performance. On the other hand, this study did not investigate other factors that may affect performance. Nasiri et al. (2011), who investigated the effects of DS between sets on the bench press, a traditional resistance training exercise, noted that increased waste metabolite removal and substrate delivery promoted the recovery of energy sources between sets. Thus, further investigation is needed in future studies because factors other than heart rate may be affected by DS.

In this study, there were no significant differences in vertical jump performance in set 1 across the conditions, indicating no effect of DS before exercise in the FULL and PREconditions. This may have been because the number of repetitions of DS performed before exercise was inadequate. Christensen et al. (2008) used eight DS exercises for the lower limb muscles, performing the same number of repetitions as in our study, and examined the effect on subsequent performance. The results showed that DS did not improve performance. Thus, the number of repetitions of DS before exercise in our study may have been insufficient to improve performance. However, in our study, the number of repetitions of DS was determined considering two factors; the rest duration between the sets is limited, and the recommended the number of repetitions in competitive and training settings (Gil et al., 2019). A study has shown the performance-enhancing effects of DS with the same number of repetitions used in our study (McMillian et al., 2006). In addition, a review by Oppler et al. (2018) noted that there is not yet any clear indicator for the number of repetitions of DS should be performed to enhance performance. Therefore, it is considered necessary to further examine the adequate repetitions of DS in future studies; however, it has been suggested that if the number of repetitions of DS is increased, the effect of fatigue may not only cancel out the subsequent improvement in performance, but may even decrease performance (Turki et al., 2012). Furthermore, it has also been suggested that the effects of DS last only about 5 minutes (Kruse et al., 2013; Smith et al., 2018). Considering these factors and the results of this study, it would be useful and practical to conduct future investigations to determine the optimal number of repetitions of DS to be performed, keeping in mind that DS should be performed not only before exercise but also between sets.

Finally, there is still a lack of research on the effects of DS performed before and between the sets of exercises. Thus, future research is suggested to examine both the factors that contribute the performance enhancing effect of the DS performed between the sets of exercises, and the more effective number of repetitions of DS to enhance performance. In addition, further investigation will be needed for the effects of DS on sprint performance, maximum muscle strength, power production using other jump exercises or weightlifting exercises, or other performance indicators that simulate competitive situations. Furthermore, with further investigation, the effects of DS may be expected to be applied not only in training but also in team sports. In team sports, some athletes may have to wait on the bench for a long time after warm-up before getting a chance to perform. In some sports, such as basketball, volleyball, and futsal, the athletes may sub in and out repeatedly. Considering the duration of the effects of DS, performing DS while waiting on the bench may improve subsequent performance.

CONCLUSION

Performing some DS for 10 repetitions between the sets of exercises, in addition to performing them before exercise, can produce higher power output in vertical jump performance in the latter half of multiple sets. This may result in a greater training effect than passive rest between sets. Thus, performing DS between sets may be an effective inter-set strategy when performing plyometric training.

AUTHOR CONTRIBUTIONS

Study concept and design, drafting the article and its critical revision: Yuji Iida. Data collection, English editing, final approval of the version to be published: Ichiro Watanabe. Data collection, final approval of the version to be published: Naoto Yoshida. Data collection, final approval of the version to be published: Kohei Iijima. Data collection, final approval of the version to be published: Hiromu Sato. Conception and design of the study, final approval of the version to be published: Akira Maeda. All co-authors have contributed to the published work and agree to its publication in Journal of Human Sport and Exercise.

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No potential conflict of interest was reported by the authors.

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