

# Difference of neuromuscular responses by additional loads during plyometric jump

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Plyometric training is a training method to increase the motor output, stretch-shortening cycle which could be associated with power output. To increase the neuromuscular output, various training variables have been incorporated in training programs. Weight vest is one of the variables to develop it. However, how much load can effectively develop the neural response is still not clearly understood. The aim of this study was to identify the effects of additional external loads on neuromuscular response of lower body during plyometric jump. Total 19 men performed jump tests with weight vest (two jumps in each additional load; 0%, 10%, 15% and 20% of bodyweight [BW]). During the tests, neuromuscular responses of lower extremity were measured. In vertical jump, 0%BW group was higher than the other heavier loads. In rate of force

development (RFD), 10%BW was higher than 15%BW and 20%BW. In 0–30 msec of interval RFD, the heavier load groups were greater than 0%BW and in 0–50 msec, 15%BW and 20%BW were higher than 0%BW. In neuromuscular efficiency (NME), 15%BW and 20%BW were greater than 0%BW in ankle joint. This research indicated that plyometric jump with additional load causes greater RFD and NME of lower extremity compared with jump training without additional load. During weight vest plyometric jump, 10%–20% of BW load is advantageous to NME of lower body and 10% of BW load is effective to develop RFD of lower extremity.

**Keywords:** Plyometric training, Weight vest, Power, Neuromuscular efficiency, Rate of force development

## INTRODUCTION

Plyometric training is one of popular training methods to enhance sports performance (Markovic, 2007) and has been known to increase the motor output, stretch-shortening cycle (SSC) which could be associated with power output and force production (Komi and Bosco, 1978).

Previous researches reported that plyometric training enhances many sports performance variables such as muscle strength, power, vertical jump height, agility, sprint performance, and neuromuscular response (Faigenbaum et al., 2007; Fouré et al., 2012; Guilhem et al., 2010; Häkkinen, 1994; Rahman and Naser, 2015) and plyometric jump training is effective to increase performance and prevent injuries from games or repetitive practices (Aboodar-da et al., 2014; Wilkerson et al., 2004).

The SSC is important neuromuscular function to produce power (Leukel et al., 2008). It consists of eccentric (stretch), amortiza-

tion, and concentric (shortening) phase. In eccentric phase that musculotendinal portion is lengthened, potential elastic energy in muscles and tendons is stored from the lengthening (Nichols and Houk, 1976) and in concentric contraction phase, explosive force or power takes place through release of the elastic energy transferred from the lengthening (Komi and Bosco, 1978). Amortization is the time between the end of lengthening phase and the initial of concentric phase and when the time is delayed, the amount of elastic energy stored in the muscles and tendons is decreased. As a result, the neuromuscular ability to produce force and power can be diminished (Bosco and Komi, 1979; Moore and Schilling, 2005).

To increase the neuromuscular output during plyometric training, various training variables (jump height, landing surface, loads, training tools, etc.) have been incorporated to training programs. Applying additional load was suggested as the best training stimulation to develop power output (Hoffman et al., 2005).

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Received: August 26, 2018 / Accepted: November 9, 2018

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On the other hand, optimal level of load application is critical to maximize neuromuscular responses which enhance power output (Barnes et al., 2015; Fatouros et al., 2000; Kraska et al., 2009).

However, it has been reported that during plyometric jump, additional load can increase ground contact time and the delayed contact time is associated with the neuromuscular responses (Santos-Concejero et al., 2013). The longer ground contact time caused by heavy load results in decrease of neuromuscular efficiency (NME) to produce power (Sáez-Sáez de Villarreal et al., 2010).

Although using additional loads in plyometric training is prevalent, how much load can effectively develop neuromuscular output through plyometric training is still not clearly understood (Leontijevic et al., 2012). Thus, this study aimed to identify the effects of additional external loads on neuromuscular response of lower body during jumping and how much additional load works for enhancing neuromuscular output during plyometric jump training.

## MATERIALS AND METHODS

### Participants

Total 20 collegiate male subjects participated in this research. Measurement data of 19 subjects, except for 1 subject who had a problem on jump, was used for analyzing the results of this study (Table 1). The subject who had problem on cardiovascular and neuromuscular functions for last 6 months before this study and on jump and landing motions was excluded from this research. All subjects were informed of the potential risks associated with this experiment before the test. This study was reviewed and approved by the committee on research ethics of the Kookmin University before all the procedures began (KMU-201507-HR-064-R1).

### Measurements procedure

All subjects performed countermovement jump (CMJ) with weight vest. 4 different external loads (0%, 10%, 15%, and 20% of bodyweight [BW]) were used for this study. 2 CMJ tests at

each additional load were carried out. 5-min rest was provided between tests of different additional loads to prevent fatigue from jumps. During the jump tests, peak power was measured using GymAware (Kinetic Performance Technology, Canberra, Australia). Vertical jump height, muscle onset time, rate of force development (RFD) and NME of knee and ankle joints were measured using electromyography (EMG) and motion analysis system.

### Electromyography

Muscle activation during CMJ was measured by using a wireless EMG device (BTS FREEEMG 1000, BTS Bioengineering, Milano, Italy). Prior to attachment of electrodes, the skin was shaved and cleaned using alcohol. The electrodes were attached to rectus femoris (knee) and soleus (ankle) of the dominant lower extremity. The EMG data was full-wave rectified and low-pass filtered at 50 Hz. Raw EMG signals were collected with a band-pass filter of 20–500 Hz, sampled at 1,000 Hz and rectified. 3 standard deviation above the mean activity on 100 msec of resting period was used to determine onset time of EMG activity.

### Motion analysis

Joint moments of knee and ankle and maximal vertical jump height were measured using motion capture analysis. The three-dimensional kinematics of the lower extremity were evaluated during CMJ using eight infrared cameras (250 Hz Oqus 5, Qualisys, Göteborg, Sweden). Qualisys track manager (QTM, Qualisys) was used for collecting data. Markers were attached to greater trochanter (GT), anterior superior iliac spine, iliac crest, posterior superior iliac spine, sacrum, medial/lateral epicondyle of the femur, medial/lateral malleolus, calcaneous and 1st, 2nd, and 5th head metapalanges of the foot.

### Data processing

RFD was evaluated by two types of RFD: (a) RFD to peak EMG amplitude (RFD<sub>peak</sub>) and (b) interval RFDs in time intervals of 0–30, 0–50, and 0–200 msec relative to start of jump (RFD<sub>interval</sub>) (Aagaard et al., 2002).

NME was defined as the ratio of joint moment to muscle activation (Aragão et al., 2015). NME was calculated by the equation;  $NME = \Sigma \text{work (torque)} / \Sigma \text{muscle activation}$ . NME of knee and ankle joints were evaluated.

Vertical jump height was determined by difference of heights of GT at start position and at maximal jump. To calculate vertical jump height, height of GT at standing position to start jump and maximal height of GT during jump were measured.

**Table 1.** The characteristics of the subjects

Characteristic	Mean ± SD
Age (yr)	24.37 ± 1.57
Height (cm)	177.24 ± 7.32
Weight (kg)	77.23 ± 11.29
%Bodyfat (%)	16.04 ± 5.33
Body mass index (kg/m <sup>2</sup> )	24.48 ± 2.79

SD, standard deviation.

**Table 2.** Vertical jump, peak power, and muscle onset time by additional loads

Variable	0%	10%	15%	20%	Post hoc
Vertical jump height (cm)	45.33 ± 4.92	41.95 ± 4.35 <sup>a,b</sup>	40.69 ± 4.05 <sup>c</sup>	39.09 ± 3.95 <sup>d</sup>	10% ( $P=0.019$ ) 0% > 15% ( $P=0.002$ ) 20% ( $P=0.000$ ) 10% > 15% ( $P=0.046$ )
Peak power (W)	7,090.05 ± 2,074.10	6,218.61 ± 1,825.28	5,924.18 ± 1,667.41	5,710.50 ± 1,604.81	NS ( $P=0.101$ )
Muscle onset time (msec)					
Knee (RF)	254.56 ± 48.99	242.29 ± 78.32	257.55 ± 72.82	253.58 ± 80.26	NS ( $P=0.918$ )
Ankle (Sol)	278.68 ± 75.08	292.50 ± 281.58	281.58 ± 97.69	295.66 ± 78.24	NS ( $P=0.908$ )

Values are presented as mean ± standard deviation.

NS, not significance; RF, rectus femoris; Sol, soleus.

<sup>a</sup>0% vs. 10%,  $P<0.05$ . <sup>b</sup>10% vs. 15%,  $P<0.05$ . <sup>c</sup>0% vs. 15%,  $P<0.01$ . <sup>d</sup>0% vs. 20%,  $P<0.001$ .

Peak power was measured by using GymAware power system (GymAware, Kinetics, Australia). Strap of the device was connected to the waists of the subjects. Maximal value of powers measured during 2 CMJ tests was recorded as peak power value.

### Statistical analysis

All data from this study was analyzed by IBM SPSS ver. 18.0 (IBM Co., Armonk, NY, USA). All values were expressed as mean and standard deviation. One-way analysis of variance (ANOVA) was performed to analyze the difference of neuromuscular responses by additional loads during CMJ. When there are significant differences between groups, least significant difference was carried out for *post hoc* analysis. Significant level was set at  $\alpha=0.05$ .

## RESULTS

### Vertical jump height

There were significant differences in vertical jump height among the groups ( $P=0.000$ ). In the *post hoc* test, 0%BW group was higher than 10%BW ( $P=0.019$ ), 15%BW ( $P=0.002$ ), and 20%BW groups ( $P=0.000$ ). The 10%BW group was greater than 20%BW group ( $P=0.046$ ) (Table 2).

### Peak power

During CMJ, peak power was assessed by GymAware power testing system. Peak powers by increase of additional loads were gradually decreased. However, the differences of peak power were not statistically significant ( $P=0.101$ ) (Table 2).

### Muscle onset time

Muscle onset times of rectus femoris in knee joint and soleus in ankle joint were evaluated during the CMJ tests. The differences

in muscle onset times of rectus femoris ( $P=0.918$ ) and soleus ( $P=0.908$ ) by the additional loads were not statistically significant (Table 2).

### Rate of force development

To evaluate RDF by additional loads, RFD to peak EMG amplitude ( $RFD_{peak}$ ) and Interval RFD ( $RFD_{interval}$ ) were tested. In  $RFD_{peak}$ , it was shown that  $RFD_{peak}$  were significantly different in the rectus femoris during the jump ( $P=0.032$ ). In the *post hoc* test,  $RFD_{peak}$  of 10%BW group was greater than 15%BW ( $P=0.014$ ) and 20%BW groups ( $P=0.010$ ). There were no significant differences in  $RFD_{peak}$  of the soleus among the groups ( $P=0.903$ ) (Table 3, Fig. 1).

In  $RFD_{interval}$ , the ANOVA showed that there were significant differences in  $RFD_{interval}$  of rectus femoris at 0–30 msec ( $P=0.019$ ) and 0–50 msec ( $P=0.037$ ). In the *post hoc* test, the heavier loads groups (10%BW [ $P=0.012$ ], 15%BW [ $P=0.045$ ], and 20%BW [ $P=0.004$ ]) were higher than 0%BW group in  $RFD_{interval}$  of 0–30 msec interval. In 0–50 msec interval,  $RFD_{interval}$  of 15%BW group ( $P=0.020$ ) and 20%BW group ( $P=0.008$ ) were significantly greater than 0%BW group. In  $RFD_{interval}$  of soleus muscle, those heavier load groups were likely greater than 0%BW group at all intervals of 0–30, 0–50, 0–100, and 0–200 msec. However, there was no significant difference among the groups in the intervals (0–30 msec,  $P=0.357$ ; 0–50 msec,  $P=0.478$ ; 0–100 msec,  $P=0.762$ ; 0–200 msec,  $P=0.236$ ) (Table 3, Fig. 2).

### Neuromuscular efficiency

As shown in Table 4, NME of ankle joint was statistically different by additional loads ( $P=0.044$ ). In the *post hoc* test, 15%BW group ( $P=0.024$ ) and 20%BW group ( $P=0.009$ ) were greater than 0%BW group. NME of knee joint was also increased when

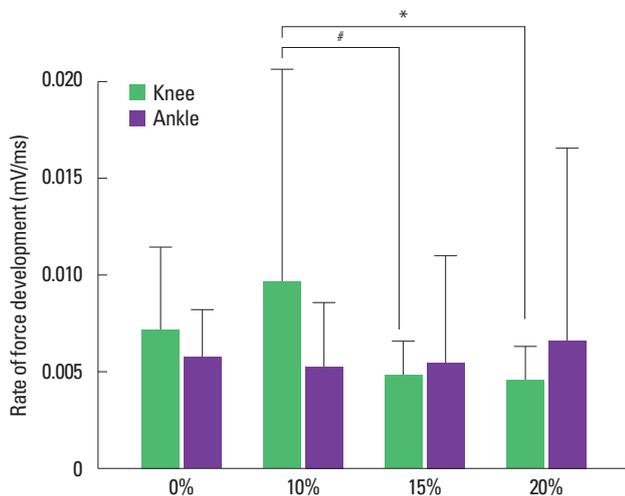
**Table 3.** Rate of force development (RFD) of knee and ankle by additional loads

Variable		0%	10%	15%	20%	Post hoc	
RFD <sub>peak</sub> (mV/msec)	Knee	0.007 ± 0.004	0.010 ± 0.011 <sup>b,c</sup>	0.005 ± 0.005	0.005 ± 0.002	10% > 15% ( <i>P</i> =0.014) 10% > 20% ( <i>P</i> =0.010)	
	Ankle	0.006 ± 0.003	0.005 ± 0.003	0.005 ± 0.007	0.007 ± 0.010	NS ( <i>P</i> =0.903)	
RFD <sub>interval</sub> (mV/msec)	Knee	30 msec	0.033 ± 0.000	0.037 ± 0.006 <sup>a</sup>	0.036 ± 0.004 <sup>b</sup>	0.004 ± 0.004 <sup>e</sup>	10% ( <i>P</i> =0.012) 0% < 15% ( <i>P</i> =0.045) 20% ( <i>P</i> =0.004)
		50 msec	0.020 ± 0.000	0.021 ± 0.003	0.022 ± 0.002 <sup>d</sup>	0.022 ± 0.002 <sup>e</sup>	0% < 10% ( <i>P</i> =0.020) 0% < 15% ( <i>P</i> =0.008)
		100 msec	0.010 ± 0.000	0.011 ± 0.001	0.0011 ± 0.001	0.011 ± 0.001	NS ( <i>P</i> =0.077)
		200 msec	0.005 ± 0.000	0.006 ± 0.001	0.006 ± 0.001	0.006 ± 0.001	NS ( <i>P</i> =0.062)
	Ankle	30 msec	0.033 ± 0.000	0.037 ± 0.009	0.038 ± 0.011	0.004 ± 0.011	NS ( <i>P</i> =0.357)
		50 msec	0.020 ± 0.000	0.022 ± 0.005	0.022 ± 0.006	0.022 ± 0.006	NS ( <i>P</i> =0.478)
		100 msec	0.010 ± 0.000	0.010 ± 0.002	0.011 ± 0.003	0.010 ± 0.002	NS ( <i>P</i> =0.762)
		200 msec	0.005 ± 0.000	0.005 ± 0.001	0.005 ± 0.001	0.006 ± 0.001	NS ( <i>P</i> =0.236)

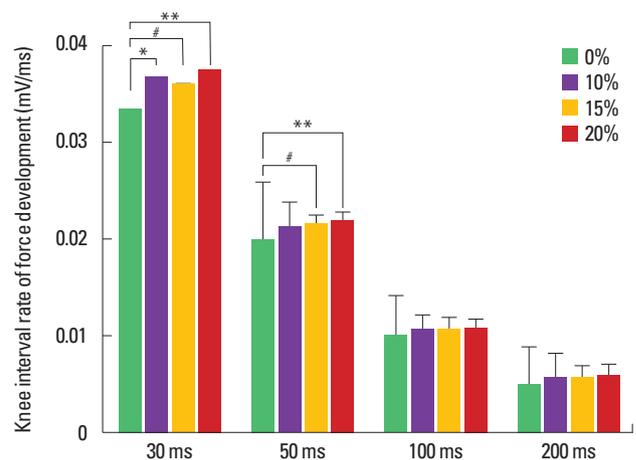
Values are presented as mean ± standard deviation.

RFD<sub>peak</sub>, RFD to peak EMG amplitude; RFD<sub>interval</sub>, interval RFDs in time intervals relative to start of jump; NS, not significance.

<sup>a</sup>0% vs. 10%, *P*<0.05. <sup>b</sup>0% vs. 15%. *P*<0.05. <sup>c</sup>0% vs. 20%, *P*<0.05. <sup>d</sup>10% vs. 15%. *P*<0.05. <sup>e</sup>0% vs. 20%, *P*<0.01.



**Fig. 1.** Rate of force development (mean ± standard deviation) by additional loads. \**P*<0.05, 10% vs. 20%. #*P*<0.05, 10% vs.15%.



**Fig. 2.** Interval rate of force development (mean ± standard deviation) by additional loads. \**P*<0.05, 0% vs. 10%. #*P*<0.05, 0% vs.15%. \*\**P*<0.01, 0% vs. 20%.

**Table 4.** Neuromuscular efficiency of knee and ankle by additional loads

Neuromuscular efficiency (Nm/mV)	0%	10%	15%	20%	Post hoc
Knee	1.15 ± 0.27	1.24 ± 0.32	1.28 ± 0.32	1.30 ± 0.33	NS ( <i>P</i> =0.478)
Ankle	1.09 ± 0.16	1.22 ± 0.27	1.30 ± 0.30 <sup>a</sup>	1.33 ± 0.34 <sup>b</sup>	0% < 15% ( <i>P</i> =0.024) 0% < 20% ( <i>P</i> =0.009)

Values are presented as mean ± standard deviation.

NS, not significance.

<sup>a</sup>0% vs. 15%, *P*<0.05. <sup>b</sup>0% vs. 20%, *P*<0.01.

additional load was more increased. However, the differences among the groups were not statistically significant ( $P = 0.478$ ).

## DISCUSSION

Plyometric training is popular in sports training to develop motor output, SSC which is related to power and force production (Komi and Bosco, 1978). To increase the neuromuscular output during plyometric training, additional training loads has been incorporated in training programs (Barnes et al., 2015; Kraska et al., 2009).

Additional load during plyometric jump, however, can increase a ground contact time and the increased ground contact time decreases neuromuscular function to produce power (Sáez-Sáez de Villarreal et al., 2010; Santos-Concejero et al., 2013). In plyometric jump training with additional load, setting appropriate additional load is crucial to effectively develop and maximize neuromuscular output.

Thus, this study was performed to identify the effects of additional loads on neuromuscular responses of lower body during plyometric jump and to clarify how much additional load works for enhancing the neuromuscular function.

Vertical jump height is typical variable to assess power ability. In this study, vertical heights of the heavier groups were gradually decreased by increase of additional loads of weight vests. It was shown that 0%BW group was higher than the heavier groups (10%BW, 15%BW, and 20%BW).

Heavy additional load seemed to negatively influence on vertical jump. During jump test, the inertia of body increased by added load decreases jumping ability (Cormie et al., 2010). Velocity of movement is a key factor to produce muscle power and RFD (Makaruk et al., 2010; Pereira et al., 2012). The increased inertia caused by the loads of the vests declines a velocity of jump movement and consequently leads to a reduction of power production (Cormie et al., 2008).

Peak power and muscle onset time were not statistically different among the groups. Although there was no significant difference in peak power, it was shown that peak powers in the heavier load groups were reduced. This result also arised from the loads of weight vests. Muscle onset time that is known as effective variable to evaluate how much muscle can quickly activate was assessed during CMJ (Riemann et al., 2002; Vasseljen et al., 2012). The significant differences by additional loads were not appeared. An evaluation of onset time after descending phase of jump in this study had a limitation to identify the muscle activation. In future

research, the static starting position would be more effective to assess muscle onset time during jump test (Myers et al., 2003).

RFD means the development of maximal force in minimal time and has been typically defined as an index to assess explosive strength and neuromuscular function (Aagaard et al., 2002; Gruber and Gollhofer, 2004). Also, RFD is known as importance performance variable to evaluate power ability (Van Hooren and Bosch, 2016). In this study, 10%BW group was greater than 15%BW group and 20%BW group in RFD to peak EMC amplitude ( $P < 0.05$ ). It means that the increased inertia from the weight vests decreases the jump velocities of the heavier groups (15%BW, 20%BW) and consequently, RFD<sub>peak</sub> of the heavier groups were less than 10%BW group (Pereira et al., 2012; Phillips and Flanagan, 2015). In previous studies, it was reported that added load during jump test reduces jump velocity and peak power and the acceleration of power production was also decreased as additional load was increased (Cormie et al., 2008; Driss et al., 2001). On the other hand, despite of nonsignificant difference between 0%BW and 10%BW in RFD<sub>peak</sub>, 10%BW group was showed higher than 0%BW group. It can be explained that appropriate additional load can work for power production, when fast movement velocity during jump can be maintained. It was reported that a resistance training with high velocity can more effectively develop RFD and muscle power compared with lower velocity training (Balachandran et al., 2014; Schoenfeld et al., 2016).

In interval RFD (RFD<sub>interval</sub>), heavier load groups (10%BW, 15%BW, and 20%BW) were higher than 0%BW group at 0–30 msec and 0–50 msec time intervals ( $P < 0.05$ ). It means that in the initial phase of jump, greater force is required to start jump quickly in the heavier load groups, because greater development of force and power has to be produced to overcome greater inertia from heavier load (Djuric et al., 2016). Additional load during jump gives rise to increase of eccentric velocity on descending phase and the increased velocity contribute to reflexive mechanism that increases stiffness in muscle and tendon to protect them from injury (Aboodarda et al., 2014; Leukel et al., 2008; McBride et al., 2008) and the increased stiffness intensifies elastic energy generating explosive concentric contraction through stretching-shortening cycle (Argus et al., 2011; Cowan et al., 2001). As a result, by plyometric jump with additional load, the ability to produce power and to increase RFD can be developed.

NME is defined as a ratio of joint moment to muscle activation and is known as an effective variable to evaluate neuromuscular function (Aragão et al., 2015; Bradbury-Squires et al., 2015; Tesch et al., 1990). This variable can be considered as an ability to

generate a joint moment in relation to muscle activation. Greater joint torque with lower muscle activation can be more efficient (Deschenes et al., 2002).

In this study, it was revealed that 15%BW and 20%BW groups were greater than 0%BW group in NME of ankle joint ( $P < 0.05$ ). Although nonsignificant difference between 10%BW and 0%BW was found, NME of 10%BW group also showed higher than 0%BW group. In knee joint, neuromuscular efficiencies of the heavier groups showed higher than 0%BW group. It is showed that additional heavy load applied to the body during jumping causes greater inertia in the heavier groups. The increased inertia and fast eccentric contraction result in higher joint moment and then gives rise to enhancement of NME. When load to joint increases, joint stiffness increases in order to reduce negative joint moment and power (Verniba et al., 2017). The stiffness prevents excessive lengthening of structures such as muscle, tendon and ligament, to protect them from the lengthening and simultaneously, enhances SSC effect during eccentric phase of jump (Hughes and Watkins, 2008; Janssen et al., 2012; Makaruk et al., 2010). When heavy load is applied, the protective mechanism that prevents joints flexed or extended excessively, when the body goes down during jump takes place to control center of mass of body and protect structures such as muscle, tendon, or ligament etc. from the load (Leukel et al., 2008).

In force-length principle, the mechanism can place a joint on the appropriate position where muscle can produce greater force (Verniba et al., 2017). The heavier groups generated greater joint moment through the mechanism to control relative greater load compared with 0%BW group. The groups take advantage of it the joints place appropriate length position to generate force greatly. Thus, the enhanced joint moment during jump by additional load is advantageous to increase NME.

By the findings of this study, it can be suggested that additional heavy load during plyometric jump training results in enhancement of RFD and 10% of BW is better as additional load to maximize RFD during CMJ jump compared to the other additional loads. Previous research also reported that plyometric training with using 10%–11% of BW load was effective to enhance a jump ability and power (Luebbbers et al., 2003).

This study, however, has some considerations. During the research, jump technique of participants was not controlled. One who has a poor jumping technique might have a problem to control the given loads. Also, percentage of load of weight vest can be changed due to adaptation to training. Thus, additional load has to be monitored and adjusted during plyometric training program.

In conclusion, using additional load during plyometric jump is effective for increase of RFD and NME of lower extremity. Previous studies indicated that weighted-vest jumping is shown to cause development of jump performance in athletic population (Burkett et al., 2005; Thompsen et al., 2007). In this study, it can be indicated that in plyometric jump training with weight vest, additional 10%–20% load of BW is more effective to develop a neuromuscular response of lower body. 10% load of BW is especially better to develop RFD compared to other additional loads.

## CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

## ACKNOWLEDGMENTS

The author appreciates the subjects for participating in this study. The helps of Dr Hong, Dr Hahn, Yongsuk, Dr Hinkel-Lipsker, Dr Li, Dr Nakamura, JD, Coach K, and In-young are much appreciated. This research was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2015S1A5B5A07044575).

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