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The immediate Effects of Flexi-bar Exercise on Plantar Pressure and Center of Pressure in Standing Position

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Abstract

Background: This study aimed to investigate the immediate effects of Flexi-bar exercise on plantar pressure and Center of Pressure in a standing position.

Design: Single group pre-post test design

Methods: Thirty healthy adult participants aged 20 to 35 years old and no recent musculoskeletal injuries were included in this single-group pre-post design study. Plantar pressure and COP data were collected using the WinTrack system before and after Flexi-bar exercise. Participants performed Flexi-bar exercises in both anterior-posterior and lateral directions for 30 seconds each.

Results: The results revealed significant changes in plantar pressure and COP after Flexi-bar exercise. The support area of the left foot significantly increased ($p<0.05$), and a significant decrease in mean pressure was observed in the right foot ($p<0.05$). The total COP path length and area significantly decreased ($p<0.05$). Furthermore, there was a significant decrease in COP velocity along the X and Y axes ($p<0.05$). These findings suggest that Flexi-bar exercise can enhance plantar pressure distribution and COP movement patterns, contributing to improved balance ability.

Conclusion: Flexi-bar exercise, performed in a standing position, has the potential to improve plantar pressure and COP characteristics. This exercise may serve as a valuable tool for enhancing balance ability. Further research is needed to explore the long-term effects and sustainability of these improvements.

Key words: Flexi-bar exercise, plantar pressure, Center of Pressure, balance ability, standing position

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Ⅰ. Introduction

Balance ability can be divided into static balance ability, which involves maintaining posture when the body is not moving, and dynamic balance ability, which involves maintaining posture while the body is in motion and dealing with changes in the supporting surface(Winter, Patla, & Frank, 1990). For optimal performance of balance ability, there needs to be stable and agile integration within the central nervous system for visual, auditory, vestibular, and proprioceptive sensory information. Additionally, various functional factors such as sufficient muscle strength, muscle tension, muscle endurance, and joint flexibility should be in place to ensure postural stability(Laufer & Dickstein, 2007).

Various intervention methods have been applied to enhance balance ability through exercise. Among them, vibration-based training, which stimulates various proprioceptive sensations while also expecting improvements in muscle strength and endurance, is being applied in various forms. Exercise using a sling involves performing sensory and motor training on a swaying strap and an unstable surface, allowing for active movement concepts and the integration of sensory and motor effects. It is a therapeutic approach that can be applied very effectively(Abercromby et al., 2007; Alashram, Padua, & Annino, 2019; Lee, Kim, & Lee, 2016; Melnyk, Kofler, Faist, Hodapp, & Gollhofer, 2008). Whole-body vibration exercise involves standing on a vibrating platform or placing parts of the body on it to provide vibration stimulation to the entire body. It is known for its various effects that can be expected through the manipulation of vibration frequencies, allowing for artificial control of gravitational loads(Brunetti et al., 2006).

Whole-body vibration exercise is particularly known for its potential benefits, including rapid and strong contractions and changes in muscle length and tension, enhanced activation of muscle spindles, stimulation of joint proprioceptors through repetitive stimuli, central nervous system stimulation through mechanical sensory receptors activation, improved muscle strength through repeated contractions, enhanced proprioception, and ultimately improved balance and posture control(Abercromby et al., 2007). Additionally, one can expect enhanced sensory stimulation of muscle and skin receptors, increased secretion of neurotransmitters, improved energy metabolism, elevated body temperature, and enhanced bone density as potential benefits(Moezy, Olyaei, Hadian, Razi, & Faghihzadeh, 2008).

Flexi-bar is designed with unique elastic properties, such that when it is moved with small amplitudes, it generates vibrations at a frequency of 5Hz. Users need to maintain a physically stable state while using it to ensure that the vibrations are transmitted throughout the body. (Kim, So, Bae, & Lee, 2014; Lee et al., 2016). Exercise using Flexi-bar is known to be effective for muscle relaxation and stabilization, increasing joint range of motion, stimulating deep muscles, and improving muscle strength. It's also known for its potential in pain relief and is used for purposes such as improving balance control, strengthening core muscles, and enhancing endurance(Chung, Park, Kim, & Park, 2015; Kim et al., 2014; Lee et al., 2016).

Many previous studies have provided evidence for the effectiveness of Flexi-bar exercise. However, research examining changes in the body's COP and plantar pressure during Flexi-bar manipulation in various directions while performing exercises has been limited. Therefore, this study aims to investigate the changes in the body's COP patterns and analyze the effects on balance ability based on the direction of Flexi-bar manipulation during exercise.

Ⅱ. Methods

This study was designed as a single group pre-post test study. This study was conducted targeting students at A college located in Andong, Gyeongsangbuk-do. To minimize individual differences in body COP changes, the criteria included a BMI of 21 or below and no musculoskeletal injuries in the past 6 months. All participants voluntarily signed the consent form after receiving an explanation of the purpose and details of this study. Additionally, they were informed that they could withdraw their participation at any time if they wished.This study was conducted after approval from the Andong Science College IRB(IRB 70365-202307-002-03).

In this study, two directions of Flexi-bar exercise were chosen to observe changes in the body's COP during the exercises. The first condition involves shaking the Flexi-bar back and forth. To perform this movement, participants were instructed to maintain an upright posture with slightly bent knees, ensuring that the knees did not protrude forward beyond the toes. Additionally, participants were guided to induce appropriate tension in the core muscles to prevent excessive front-back curvature of the spine. All participants performed the pre-test and flexi-bar conditions in barefoot.

Participants were instructed to position the Flexi-bar horizontally relative to their bodies and grasp the central part with both hands. They ensured that the center of the Flexi-bar was positioned between the chest and the navel. Then, they were asked to generate short and rapid vibrations in the forward and backward directions while shaking the Flexi-bar for 30 seconds. The second Flexi-bar exercise involves shaking it from lateral-lateral. Similar to the first condition, participants were instructed to stand in an upright position and hold the Flexi-bar vertically, ensuring it was parallel to their bodies. They gripped the Flexi-bar's handle with both hands. With the navel as the reference point, they were asked to shake the Flexi-bar from lateral-lateral rapidly for 30 seconds, making sure not to extend beyond the sides of their torso. A 30 seconds break time was povided after pre-test and a 1 minute break time was provided beween flexi-bar conditions. All participants instructed on pelvic and trunk posture to maintain appropriate pressure in the abdomen and to prevent the formation of excessive spinal angles such as lordosis and kyphosis. In this study, a flexi bar with a length of 153 cm and a weight of 650 g was used. A flexi bar is a carbon fiber rod with weights on both ends and has an average vibration frequency of 5Hz.

Outcome measures

In this study, WinTrack equipment from Medicapteurs, France, was used to evaluate changes in the body's COP and plantar pressure during Flexi-bar exercises. This equipment is designed with 12,288 sensors on a 120cm measurement plate, capable of capturing 200 images per second (200Hz). In this study, the evaluation of body's COP movement patterns, including body sway distance, body sway area, anterior-posterior and medial-lateral sway velocities while standing in an upright position, was conducted both in the pre-assessment and under different Flexi-bar exercise conditions. Additionally, numerical values related to plantar pressure, including the pressure area of the left and right feet and weight distribution ratio, were analyzed. To conduct the pre-assessment of the body's COP and plantar pressure, measurements were taken on the equipment for 30 seconds.

Statistics analysis

In this study, we described the general characteristics of the participants, including their age and gender, using means and standard deviations to represent the data. Paired t-tests used to compare the results before and after the Flexi-bar exercise conditions and a statistical significance level of less than or equal to 0.05 ($p < 0.05$).

Ⅲ. Result

The average age of the participants in this study was 21.67 years old, with an equal number of 15 males and females. The average height was 169.40 cm, and the average weight was 62.13 kg. The participants had an average BMI of 21.47, which falls within the normal range(Table 1).

The left foot's supporting surface area increased significantly from 111.93 in the pre-test to 115.87 in the post-test. The right foot's supporting surface area increased numerically from 115.87 in the pre-test to 118.30 in the post- test, but this change was not statistically significant. The average pressure on the left foot decreased from 287.30 in the pre- test to 282.03 in the post- test, but there was no significant change. The average pressure on the right foot decreased significantly from 286.07 in the pre- test to 269.90 in the post- test. The weight-bearing ratio on the left foot increased from 49.13 in the pre- test to 50.07 in the post- test, but this change was not statistically significant. The weight-bearing ratio on the right foot decreased from 50.87 in the pre- test to 49.93 in the post- test, but there was no significant change(Table 2).

The total COP displacement decreased significantly from 185.13 in the pre-test to 142.23 in the post- test. The total COP area reduced significantly from 377.93 in the pre- test to 183.12 in the post- test. The X velocity of COP decreased significantly from 4.25 in the pre- test to 3.51 in the post- test(Table 3). The Y velocity of COP decreased significantly from 3.61 in the pre- test to 2.74 in the post- test. The X deviation of COP decreased from 3.01 in the pre-assessment to 2.44 in the post- test, but this change was not statistically significant. The Y deviation of COP decreased significantly from 3.80 in the pre- test to 2.86 in the post- test(Table 4 & 5).

Table 1. The general characteristics of participants

	Male(*n*=15)	Female(*n*=15)	Total(*n*=30)
Ages(years)	22.27±1.39	21.07±1.62	21.67±1.61
Height(cm)	176.93±5.66	161.87±4.17	169.40±0.51
Weight(kg)	70.20±10.45	54.07±6.82	62.13±11.94
BMI	22.35±2.52	20.59±2.17	21.47±2.48

BMI : body mass index

Table 2. changes of foot pressures (n=30)

	Pre-test	Post-test	Pre-post	t	p
Left Area (cm²)	111.93±18.15	115.87±19.46	-3.93±8.76	-2.458	0.020
Right Area (cm²)	115.87±18.92	118.30±19.18	-2.43±12.48	-1.068	0.294
Left AverageP (g/cm²)	287.30±40.92	282.03±62.54	5.27±54.30	0.531	0.599
Right AverageP (g/cm²)	286.07±33.03	269.90±57.57	16.17±43.14	2.053	0.049
Left trust (%)	49.13±3.10	50.07±2.68	-0.93±3.48	-1.468	0.153
Right trust (%)	50.87±3.10	49.93±2.68	0.93±3.48	1.468	0.153

AverageP : Average pressure of foot, $p<0.05$

Table 3. changes of center of pressure (n=30)

	Pre-test	Post-test	Pre-post	t	p
Length of COP (mm)	185.13±72.21	142.23±51.87	42.90±45.45	5.169	0.000
Total area of COP (cm²)	377.93±437.99	183.12±148.47	194.81±395.94	2.695	0.012
X velocity of COP (mm/s)	4.25±1.85	3.51±1.16	0.74±1.45	2.784	0.009
Y velocity of COP (mm/s)	3.61±1.52	2.74±1.07	0.86±1.04	4.532	0.000
X deviation (mm)	3.01±1.68	2.44±1.43	0.57±1.67	1.880	0.070
Y deviation (mm)	3.80±1.88	2.86±1.77	0.94±1.56	3.289	0.003

$p<0.05$

Table 4. changes of center of pressure accordingly to direction of flexi-bar F-B (n=30)

	Pre-test	Flexi-bar F-B	t	p
COP Length (mm)	185.13±72.21	676.72±327.16	-8.245	0.000
COP Area (cm²)	377.93±437.99	887.65±1505.13	-1.974	0.058
X velocity (mm/s)	4.25±1.85	15.45±7.48	-8.639	0.000
X-deviation (mm/s)	3.01±1.68	3.94±1.86	-2.278	0.030

Flexi-bar F-B : Flexi-bar front-back condition

p<0.05

Table 5. changes of center of pressure accordingly to direction of flexi-bar L-L (n=30)

	Pre-test	Flexi-bar L-L	t	p
COP Length(mm)	185.13±72.21	1410.25±564.52	-12.082	0.000
COP Area(cm²)	377.93±437.99	1995.39±5577.19	-1.645	0.111
Y velocity(mm/s)	3.61±1.52	13.27±5.31	-10.689	0.000
Y-deviation(mm/s)	3.80±1.88	6.32±3.19	-4.691	0.000

Flexi-bar L-L : Flexi-bar Lateral-Lateral condition

$p<0.05$

Ⅳ. Discussion

Vibration exercise is being used as an effective intervention method for preventing ankle injuries and assisting in the rehabilitation of already injured ankles. It accomplishes this through improvements in muscle strength, flexibility, balance, and proprioceptive sensitivity(Brunetti et al., 2006; Moezy et al., 2008). Vibrational stimulation induces activation of proprioceptors, thereby eliciting excitability in muscle contraction-related circuits(Lebedev & Poliakov, 1991). Vibrational stimulation strongly affects alpha-motor neurons and induces reflexive muscle contractions in the muscle belly and tendons. This response is referred to as tonic vibration reflex(Bosco et al., 1999).

This study aimed to investigate the changes in plantar pressure and the pattern of the COP displacement during Flexi-bar exercise. Regarding the changes in plantar pressure due to Flexi-bar exercise, there was an increase in pressure area on both the left and right sides, with a significant difference observed on the left side. Additionally, the average pressure values decreased on both sides, but a significant difference was only observed on the right side. In this study, participants underwent pre-test, followed by 30-second sessions of Flexi- bar exercises, including front-back and lateral-lateral movements, and then post-test was conducted. Although the exercise duration with Flexi-bar was short, only 1 minute, it resulted in changes in plantar pressure, characterized by an increase in the total supporting surface area and a decrease in average pressure. These changes suggest that the front-back and lateral-lateral movements with Flexi-bar increased participants' body sway, leading to an increase in the total supporting surface area and a more even distribution of pressure across the feet(Orlin & McPoil, 2000).

Unstable tools and devices are commonly used in rehabilitation because they are effective in preventing injuries and enhancing balance abilities(Akuthota & Nadler, 2004). Utilizing tools that provide an unstable surface and induce body sway can activate balance strategies for postural control and help activate the function of tendons, ligaments, and joints(Schilling et al., 2009). In this study, changes in COP displacement during Flexi-bar exercise in both front-back and lateral-lateral conditions were measured, not only in pre-test and post-test. The results revealed that during the front-back condition, there was a significant increase in COP displacement in the front-back direction compared to the pre-test, along with significant changes in the X-axis displacement velocity and deviation. Similarly, during the lateral-lateral condition, there was a significant increase in the total COP displacement and significant changes in the Y-axis displacement velocity and deviation. These findings suggest that exercising with Flexi-bar increases the instability of body sway, as indicated by the observed changes in COP parameters, enhancing the effectiveness of balance training.

In this study, changes in COP displacement due to Flexi-bar exercise were measured. The results showed a significant decrease in the total COP displacement , as well as a significant decrease in the total COP area. There was also a significant difference in the displacement velocity of COP in the X and Y axes, indicating that the movement velocity of the COP decreased compared to before Flexi-bar exercise. The decrease in COP velocity implies that the body swayed at a slower rate, indicating an improvement in motor control for balance adjustment(Almeida, Carvalho, & Talis, 2006; Brunetti et al., 2006; Chung et al., 2015).

Proprioceptive sensitivity plays a crucial role in integrating important kinesthetic information from joint receptors, muscle spindles, and Golgi tendon organs. It provides this information to the central nervous system, facilitating normal joint movements and ensuring the safe protection of joints from external injuries(Dukelow et al., 2010). Continuous vibrational stimulation is known to stimulate proprioceptors, strengthening the muscles involved in postural stability(Bogaerts, Verschueren, Delecluse, Claessens, & Boonen, 2007). As shown in previous studies, vibrational stimulation enhances the metabolic interactions between blood and muscle fibers during its application on the body. Utilizing the benefits of these vibrations, exercise provides a strong sensory stimulus that activates proprioception and enhances proprioceptive sensitivity, thereby strengthening the essential muscles needed for postural stability(Abercromby et al., 2007; Alashram et al., 2019; Bogaerts et al., 2007; Moezy et al., 2008). The results of this study indicated that there were improvements in participants' plantar pressure and COP displacement patterns. These findings are believed to be a result of the activation of proprioceptive sensory mechanisms due to vibrational stimulation. During Flexi-bar oscillations, proprioceptive receptors experienced significantly increased signals related to muscle elongation and contraction compared to pre-exercise levels(Docherty, Arnold, Zinder, Granata, & Gansneder, 2004; Lebedev & Poliakov, 1991). As a result, the increased activation of neural circuits related to muscle contraction is believed to have led to improvements in plantar pressure and COP displacement patterns.

The limitations of this study include the small sample size, which restricts the generalizability of the results. Additionally, since this study evaluated the immediate effects of Flexi-bar exercise, further research is needed to investigate the long-term effects and the duration of these effects through follow-up studies.

Ⅴ. Conclusion

This study aimed to investigate changes in plantar pressure and COP movement through Flexi-bar exercise. The results showed an increase in the support area of the feet and a decrease in average pressure. Additionally, there was a reduction in COP path length and a decrease in movement velocity along the X and Y axes. Therefore, it can be suggested that Flexi-bar exercise, when performed in a standing position, can improve plantar pressure and COP movement patterns, making it a valuable tool for enhancing balance ability.

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