Original

Relationship between Postural Stability in Response to Perturbations and Physical Flexibility

Kouki Taniuchi

Department of Physical Therapy, Welfare General Faculty, Josai International University

(Received: June 9, 2021)

Abstract

Purpose: This study investigated the relationship between standing posture stability and physical flexibility, and to examine the role of flexibility in maintaining postural stability in response to perturbations.

Participants and Methods: Forty-five healthy individuals (25 men, 20 women; average age, 33.0 ± 9.2 years) were included. Standing posture stability was evaluated using a motion analysis system. The center of pressure sway trajectory and maximum amplitude were measured during forward surface movement, left-right, and front-back directions. Two trials were performed for each measurement. The forward reach distance from a standing position was measured and used as an index of physical flexibility.

Results: The indices of standing posture stability and physical flexibility were negatively correlated only in the second trial.

Conclusion: An internal model of feedforward control was acquired during the first trial, resulting in decreased center of pressure sway and efficient muscle activity in the second trial. This reflected improved postural control. The acquisition of this internal model requires physical flexibility. The greater the physical flexibility, the less the center of pressure sway. Improving flexibility may improve postural control and neuromuscular system function. Physical flexibility is useful in the evaluation of balance ability.

(JJOMT, 70: 1—6, 2022)

—Key words—

standing posture stability, physical flexibility, center of pressure

Introduction

Falls and fractures require long-term care even in healthy individuals. Poor balance has been associated with risk and fear of falling[1)~4)]. According to epidemiological studies on physical factors affecting long-term care, as the risk of balance impairment increases by 2.6–2.9 times, the risk of falling increases by 5 times[2)3)]. Balance ability is strongly associated with gender, age, number of falls, mental function, and muscle strength, while decreased balance ability is the strongest predictor of repeated falls with an associated increased risk of repeated falls of 3.9 times[4)]. Previous studies on fall prevention have reported that falls are associated with impaired balance[5)6)] and decreased lower-limb muscle strength[6)~8)]. In addition, fall prevention programs not only include basic exercise interventions, but also complex exercises and functional interventions[5)8)~15)]. However, the ideal content, duration, and exercise frequency for these programs have not been established. Despite disagreement regarding the influence of balance ability on the fear and risk of falling, studies have examined the role of decreased muscle strength in balance impairment[8)16)~18)]. The role of flexibility in balance has been noted[19)], but no reports describe it in detail. According to Kendall[20)], posture is related to limb and joint positions when maintaining a static position or during movement. Posture can also be described from the perspective of muscle balance. The ideal skeletal alignment that provides the ideal posture is based on sound scientific principles and is the most efficient body state with good muscle balance, minimal stress, and tension. Sato et al[21)] reported that the main cause of poor posture is muscle imbalance, that is, an imbalance of muscle strength and flexibil-

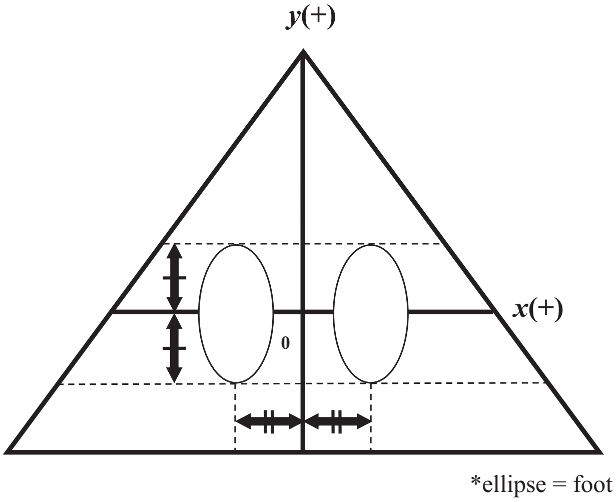

Fig. 1 Position of the feet on the force plate

ity[21]. Furthermore, imbalance of antigravity muscles increases center of gravity sway, leading to impaired posture and gait, decreased athletic ability, increased risk of injuries, and back pain[22]. However, previous studies have reported that muscle strength is unrelated to balance ability[22][23]. Our study aimed to investigate the relationship between balance ability and physical flexibility. Moreover, this study aimed to examine the role of flexibility in the evaluation of balance ability.

Participants and Methods

We enrolled 45 healthy individuals in this study, including 25 men and 20 women, with an average age of 33.0 ± 9.2 years, average height of 165.4 ± 6.8 cm, and an average weight of 64.4 ± 14.4 kg. Participants with a history of conditions that may have affected their ability to participate in the study, such as osteoarthritis, neurological disorders, and locomotor disorders were excluded.

All study procedures were carried out in accordance with the principles of the Declaration of Helsinki. Participants were informed about their rights regarding participation in the study and what measures would be taken for the protection of their personal information. They were provided with a research manual, consent form, and consent to withdrawal form and were enrolled after providing consent. The study protocol was approved by the Comprehensive Rehabilitation Iyo Hospital Ethics Review Board (Approval number 2021-1).

As an index of balance ability, we measured the center of gravity sway during standing (standing posture stability). Changes in the center of pressure (COP) were recorded, which has a high test-retest reliability of 0.71 to 0.95[24][25]. We installed a ground reaction force meter from a comprehensive motion analysis system (MA6000, Anima, Chofu City, Tokyo, Japan) on a trolley connected to an electric wheelchair. Participants were asked to stand upright facing forward with their eyes open and arms by their sides. The left-right axis (hereinafter, x-axis) passed through the center of the foot; the line connecting the trailing edges of both heels was set to be parallel to the x-axis and was evenly separated from the front-back axis (hereinafter, y-axis) (Fig. 1). The measurement time was 10 s: the electric wheelchair was kept upright for the first 3 s; thereafter, it was moved forward at 4.0 km/h for 5 s, with the measurement completed 2 s later. Participants were instructed to remain standing until a signal was given several seconds after the electric wheelchair stopped moving. Two trials were performed. Standing posture stability was determined based on the COP sway trajectory[22][26][27]. The effective value (cm) of the COP sway trajectory and the maximum amplitude (cm) of COP sway in the left-right and front-back directions were calculated. In addition, to maintain constant acceleration, the total weight on the trolley was maintained at a constant level by placing a sand sac on the trolley (participant's weight + sand sac =110 kg).

Because running involves movement in the anterior direction and forward reactions in the anterior direction are more commonly performed, physical flexibility is based on the extensibility of the muscles and tendons of the posterior trunk, lumbar region, thighs, and legs[28]. We evaluated physical flexibility in terms of the stand-and-reach distance, which is an item in the Ministry of Education, Culture, Sports, Science, and Technology sports test[29]. To measure the forward reach distance when standing, participants were asked to stand on a table. The surface of the table was considered as 0 cm; a ruler with a scale of 1 cm that extended 25 cm above and 40 cm below the surface was attached to it. With their heels on the surface and their feet approximately 5

Table 1 Correlation between body sway factors and flexibility factors

	Root mean square length (cm)		Maximum amplitude of postural sway (cm)			
			x-axis		y-axis	
	2.5 km/h	4.0 km/h	2.5 km/h	4.0 km/h	2.5 km/h	4.0 km/h
Stand-and-reach distance (cm)	$r=-0.36$, $p<0.05$	$r=-0.52$, $p<0.01$	$r=-0.41$, $p<0.05$	$r=-0.45$, $p<0.05$	$r=-0.23$, ns	$r=-0.37$, $p<0.05$
Sit-and-reach distance (cm)	$r=-0.31$, ns	$r=-0.54$, $p<0.01$	$r=-0.34$, ns	$r=-0.42$, $p<0.05$	$r=-0.21$, ns	$r=-0.36$, $p<0.05$

ns: no significant difference

cm apart, participants were asked to bend forward while touching the ruler with both hands extended; the lowest point on the ruler reached by both fingertips was noted. The higher of the two measurements obtained without bending the knee, recoiling, or extending one hand excessively was noted.

To investigate the relationship between standing posture stability and physical flexibility, Pearson's correlation analysis was performed with a significance level of 5%. Statistical analyses were performed using JSTAT software for Windows.

Results

The relationship between standing posture stability and physical flexibility is shown in Table 1. The stand-and-reach distance showed a significant negative correlation with the effective value of the COP sway trajectory ($r=-0.54$; $p<0.01$) and the maximum COP amplitude in the directions of the x- and y-axes (x-axis, $r=-0.43$, $p<0.01$; y-axis, $r=-0.37$, $p<0.05$) in the second trial. However, no correlations were found among the stand-and-reach distance and any variable in the first trial.

Discussion

Although the importance of physical flexibility in the evaluation of balance ability has been noted[19], no reports have described in detail the exact role of flexibility in balance ability. Therefore, we investigated the relationship between balance ability and physical flexibility, as well as the role of physical flexibility in the evaluation of balance ability. We observed a negative correlation among the standing posture stability and physical flexibility indices. In other words, the higher the physical flexibility, the lower the COP sway while maintaining an upright posture. This suggests that physical flexibility may be useful in the evaluation of balance ability.

In the first trial of the present study, the stand-and-reach distance was not correlated with the effective value of COP sway trajectory and the maximum amplitude of COP sway in the left-right and front-back directions.

However, in the second trial, a correlation was observed between these variables. This difference may be followed to the first trial involved only reactive postural control, whereas the second trial also involved anticipatory postural control as previously reported by Horak[30]. In other words, the difference in the results of the first and second trials reflects an improvement in postural control. We believe that the participants acquired an internal model of feedforward control during the first trial, which resulted in decreased COP sway and efficient muscle activity in the second trial. Osu[31] reported cases wherein the internal model of feedforward control was appropriately learned when performing a balance reaction, although there have been cases where this learning did not occur. Physical flexibility is important for the acquisition of this internal model. Because the participants in this study were healthy, their response to perturbation during the second trial probably involved a greater use of anticipatory postural control than the response to perturbation in the first trial. Furthermore, the greater the physical flexibility, the more rigid the feedforward control. Moreover, learning the internal model of feedforward control results in smooth movement of the center of gravity, and an upright posture can be maintained with less COP sway. The above concept can be explained by the extreme differences in the results of the first and second trials.

Improved flexibility is associated with increased extensibility of the connective tissue in muscle fibers, muscle tendons, and collagen fibers, which improves their ability to tolerate sudden loading. This prevents muscle, tendon, and ligament injury by suppressing the excitability of proprioceptors, reduces muscle tension and creates a relaxing effect enabling appropriate agonist and antagonist muscle activation and smooth movement, which improves exercise performance[32,33]. Guissard et al[33] reported that improved range of motion and joint flexibility are due to decreased connective tissue viscoelasticity in muscles, muscle tendons, and collagen fibers, which leads to muscle relaxation due to the suppression of neuromuscular excitability. Therefore, it is important to improve flexibility.

The equilibrium strategy used in response to perturbations depends on the situation[34,35]. Postural control through muscular activity is intricately involved in this response. Previous studies[36–38] on postural control have shown that responses to perturbations are not in the form of individual joint movements, but involve the coordinated activity of multiple muscles. The equilibrium strategy is considered a reaction of the neuromuscular system to chemical formation. Studies[32,33,39] have suggested that improved flexibility following stretching enhances not only exercise performance but also balance ability due to improvements in muscle work and somatosensory function. We believe that the response of the neuromuscular system to perturbations can be regarded as an index of balance ability and somatosensory function. Thus, physical flexibility (muscle flexibility) may positively affect somatosensory function, neuromuscular function, and balance. This suggests that physical flexibility may influence balance ability.

One limitation of this study is our use of the stand-and-reach distance as an index of body flexibility, the effective value of the COP sway trajectory, and the maximum amplitude of COP sway as indices of standing posture stability. It is unclear whether the relationship between physical flexibility and balance ability will be observed if different indices are used. Furthermore, physical flexibility may be affected by stretching.

In future studies, standing posture stability should be analyzed in terms of center of gravity and reported as an exercise performance index. The effects of whole-body and muscle relaxation should also be considered. We believe that the findings of this study have great potential for clinical applications and will improve physical therapy performance.

In conclusion, individuals with high physical flexibility sway less when standing than those with low physical flexibility. Therefore, improving flexibility may improve somatosensory and neuromuscular system function. Furthermore, physical flexibility is useful in the evaluation of balance ability.

Acknowledgments

We would like to thank Editage (www.editage.com) for English language editing.

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Reprint request:
Kouki Taniuchi
Department of Physical Therapy, Welfare General Faculty, Josai International University, 1, Gumyou, Togane City, Chiba, 283-8555, Japan.

別刷請求先　〒283-8555　千葉県東金市求名 1
城西国際大学福祉総合学部理学療法学科
谷内　幸喜

外乱刺激に対する立位保持能力と身体柔軟性との関連性について

谷内　幸喜
城西国際大学福祉総合学部理学療法学科

―キーワード―
立位保持能力，身体柔軟性，足圧中心

【はじめに】バランス能力としての立位保持能力と身体柔軟性との関連性を調べ，外乱刺激応答に対する身体柔軟性の有効性を検討した．【対象および方法】健常者45名（男性25名，女性20名，平均年齢33.0±9.2歳）を対象とした．立位保持能力の指標としては，アニマ社製総合動作分析システム（MA6000）を使用して前方床移動外乱中の動揺軌跡の実効値及び左右前後の最大振幅を求めた．身体柔軟性の指標としては，立位体前屈距離を測定した．立位保持能力と身体柔軟性との関連性を調べるために，それぞれにおける相関分析（Pearson）を行い有意水準を5%未満として解析を行った．【結果】立位保持能力指標と身体柔軟性指標との関係では，2回目の試行時において負の相関性が認められた．【考察】フィードフォワード制御の内部モデルが，最初の試行中に取得されたため2回目の試行では筋肉活動が効率的になり，姿勢制御機能の向上による外乱応答であったと考えられる．内部モデルの取得において柔軟性の重要性は報告されており，今回，身体柔軟性の高い人ほど少ない動揺で立位姿勢を保持していることが示された．柔軟性を改善すると，姿勢制御と神経筋系機能が改善される可能性が示唆されたことで，バランス能力評価において身体柔軟性の有効性を示したと考えられる．

［COI開示］本論文に関して開示すべきCOI状態はない

（日職災医誌，70：1―6，2022）