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Original Article

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The Effect of the Base of Support on Anticipatory Postural Adjustment and Postural Stability

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Purpose: This study was to identify the anticipatory postural adjustment (APA) mechanism which is represented by the onset time of trunk muscles and the displacement of the center of pressure (COP) according to the different base of support (BOS) during upper extremity movement.
Methods: Thirty healthy subjects (14 males, 16 females) participated in this study. The movement was performed for 10 trials during each of various BOS (shoulder - width double leg stance, narrow base double leg stance, tandem stance, non-dominant single leg stance) at the 1.2 Hz frequency. Electromyography was used to measure muscle onset time and biorescue was used to measure characteristics of the displacement of COP. Surface bipolar electrodes were applied over the right deltoid anterior, right latissimus dorsi, both rectus abdominis, both internal oblique and both erector spinae. The data were analyzed by repeated one-way ANOVA and Duncan's post hoc test.
Results: The study has revealed following. There were significant differences with muscle onset time in each BOS ($p < 0.01$). There were significant differences in characteristics of the COP in each BOS ($p < 0.01$).
Conclusion: The study found that the more narrowed the basis requires the more rapid anticipatory postural control in contralateral postural muscle when the upper extremity movement is performed.

Keywords: Anticipatory postural adjustment (APA), Base of support (BOS), Postural stability, Perturbation

INTRODUCTION

It is well known that the postural control according to postural perturbation occurs through the compensatory adjustment or the anticipatory adjustment.[1] In general, the compensatory postural adjustment occurs after external stimulation (external perturbation) and the anticipatory postural adjustment (APA) occurs before an active movement (internal perturbation).[1-3] Among them, APA acts in the opposite direction with the postural perturbation.[4] In other words, APA predicts body perturbations which are affected by body movement and then activates the musculoskeletal system in the opposite direction predicted. As a result of the mechanism, the postural perturbation become minimized. Through the mechanism, it can be explained that the postural muscle is activated before the active movements of limbs.[5] When the body moves, postural muscle act for maintaining the posture and the stability of the body.[6] The activation of postural muscle for APA is concerned with the primary motor area, supplementary area, basal ganglia of the cerebral cortex.[7] At the previous study, muscle activation of internal oblique abdominis and transverse abdominis are faster than muscle activation of anterior deltoid which is the standard of the starting movement during flexing upper extremity. According to the study of,[8] anticipatory muscle activation appears in erector spinae and both internal oblique abdominis during upper extremity extension.

The base of support (BOS) is the region of ground surface which the body contacts with. And the center of gravity (COG) is a point which the center of mass (COM) comes down perpendicularly to the BOS. Stable posture means that the COG is placed within the

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BOS.[9] The position of feet affects the stability in the standing posture.[10] In the standing position, the BOS is the area within the feet. So, the postural stability is more increased when the BOS is widened by feet.[11] In other words, the difference of base area changes the postural stability and changes the strategy of postural adjustment. The balance error scoring system (BESS) is one of the assessment tools which are designed for assessment of postural stability. It is known as an accurate, simple, and appropriate method to evaluate balance. BESS evaluates the postural stability in the position of the double leg, single leg and tandem stance. On single leg stance position, it is designed to stand using the non-dominant leg. In the study of Santos and Aruin,[12] the APA strategies with one leg standing posture and double leg standing posture are compared. It showed that the bigger postural control and the more rapid muscle activation occurs in one leg stance position than double leg standing posture. Through the study, we knew that the components of BESS can be a good scale for research on postural stability.

In the present, there were lots of researches about the APA during internal perturbation already. Furthermore, there were many previous studies of the Center of Pressure (COP) displacement characteristics or the onset time of postural muscle which is represented by APA strategy. But, there were no studies reflecting both characteristics. So, in this study, we researched about the APA strategy according to various bases during internal perturbation which is the upper extremity flexion and extension.

METHODS

1. Subjects

Thirty healthy subjects (fourteen males and sixteen females) who haven't suffered from back pain and didn't have a lesion on the upper extremities for the last one year. Their dominant hands and legs are the right side. Before participating in the research, they had received enough explanation and agreed all the research procedures voluntarily. The general characteristics of the subjects are the same as Table 1.

Table 1. General characteristics of subjects (n=30)

Characteristic		Mean±SD
Subject	Age (year)	24.07±1.34
	Height (cm)	168.63±7.01
	Weight (kg)	59.97±9.03
	Feet (mm)	248.17±14.41

SD: standard deviation.

2. Experiment equipment and measuring instrument

1) Electromyogram, EMG

The surface electromyography (WEMG, Laxt ha, USA) was used to measure the activation time of the postural muscle's contraction. This equipment consists of a transmitter and a receiver.

2) Measuring balance ability and biorescue

Biorescue is used to study the displacements of the COP and balance ability measurement. Biorescue can measure healthy people's

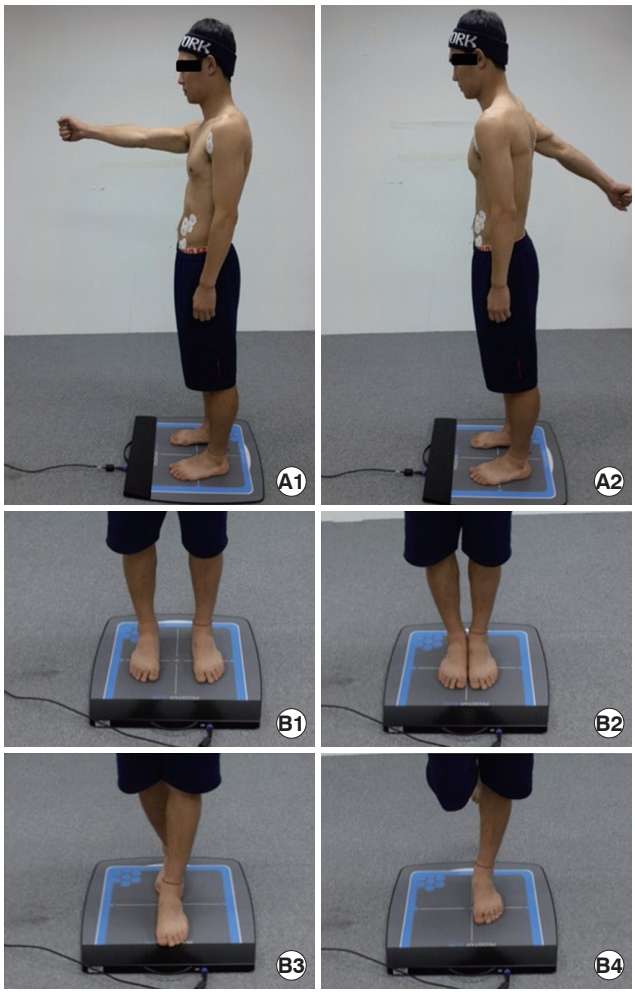

Figure 1. Experimental setup. The subjects received a perturbation at the shoulder level by the right arm swing toward flexion and extension on 4 conditions of foot position.
A1: shoulder flexion, A2: shoulder extension, B1: shoulder-width double leg stance (SD), B2: narrow base double leg stance (ND), B3: tandem stance (TS), B4: non-dominant single leg stance (SS).

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static and dynamic balance ability. And we can know displacement track's area (cm^2), length (cm) and average velocity (cm/s) of the COP displacement during specific movement through analysis of data from biorescue.

3. Experiment methods

1) Procedure

The subjects' trunk muscle activity during flexion and extension movement of the right shoulder with an extended elbow and wrist position were measured. The order of the BOS was randomized. The subjects participated in the experiment after practicing shoulder flexion and extension movement with 1.2 Hz metronome (Figure 1, A1-2).[13] Then, the subjects stopped the movement and maintained for 5 seconds and 8 seconds using an alarm to measure the reference value. The data were measured to set the reference value of muscle activation. And then, when the subjects heard the alarm which were set randomly, they performed upper extremities task. The alarm set 1.2 Hz and 10 times. To minimize the muscle fatigue, the subjects took a rest for 5 minutes after measuring each performance task.

2) Postural changes according to BOS

The subjects stand on 4 different postures having a different BOS. The 4 different postures are shoulder-width double leg stance: SD, narrow base double leg stance: ND, tandem stance: TS and non-dominant single stance: SS (Figure 1, B1-4).[5]

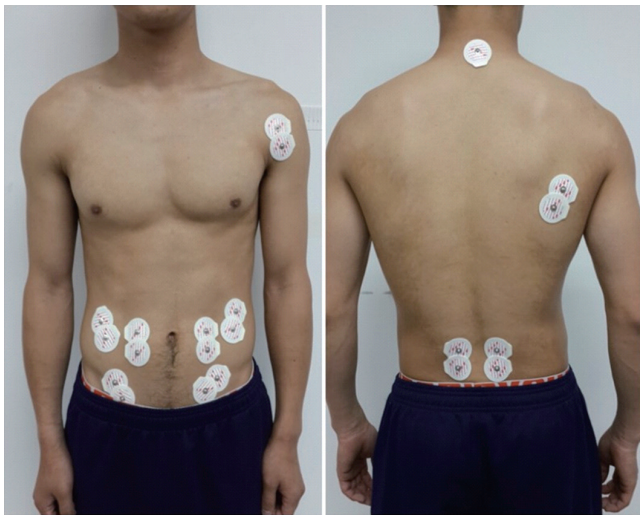

Figure 2. Electromyogram position.

3) Attachment of EMG electrode

This is attachment point of EMG electrode. Removed hairs and corneum by sand paper. A surface electrode is attached at anterior deltoid (AD), right side latissimus dorsi (LD), both rectus abdominis (RA), both internal oblique (IO), both erector spinae (ES). The ground electrode is attached to the process of C7 (Figure 2). The attachment area of the electrode has followed the indication of SANI-AM's.[14,15]

4) Recording and signal processing with EMG

Data sampling of EMG signal was 1,024 Hz and band pass filter applied to 10-500 Hz. We used the notch filter of 60 Hz, 120 Hz, 180 Hz so it removed noise. The measurement of each muscle onset time was set the exceeding 3 times of average and standard deviation during the standard line and was set as a point which the excess continuance time reaches the 500 ms.[16] During upper extremity flexion, we set the onset time of right side anterior deltoid muscle as the standard of muscle onset time. And during upper extremity extension, we set the onset time of right side latissimus dorsi as the standard of muscle onset time.[5] We regard the activation of postural muscle which is activated faster than standard muscle (right anterior deltoid, right latissimus dorsi) as the muscle activation by an APA.[17]

4. Statistical analysis

The statistical process of this study used SPSS version 19.0. The general characteristics of subjects were analyzed using the descriptive statistics. And we used the repeated one-way ANOVA for analysis of muscle activation time and characteristics of the COP displacement according to each different base when upper extremity was flexed and extended. The result values having significant difference were done post-hoc test using Duncan method. In this study, we set a value which is the statistical significance level was 0.05.

RESULTS

1. The comparison of the onset time of postural muscle and characteristics of COP displacement according to bases during shoulder flexion.

There was a significant difference in the onset time between each 4 bases which have different stability each other ($p < 0.01$).

In the post-hoc comparison result, both rectus abdominis and

Table 2. Muscle activation time of the trunk muscles according to the base of support at the right shoulder flexion and extension (Unit: sec)

	SD (A)	ND (B)	TS (C)	SS(D)	F	Post-hoc
S-Flex						
L.RA	0.45±0.26	0.01±0.34	-0.49±0.37	-1.38±0.46	139.45**	A>B>C>D
R.RA	0.47±0.27	0.00±0.38	-0.33±0.27	-1.22±0.40	137.91**	A>B>C>D
L.IO	0.40±0.30	0.20±0.50	-0.16±0.53	-0.08±0.11	8.18**	A,B>C,D
R.IO	0.38±0.27	0.15±0.66	-0.06±0.53	-0.17±0.76	5.15**	A,B>C,D
L.ES	0.17±0.42	-0.05±0.51	-0.50±0.40	-1.02±0.49	39.18**	A,B>C>D
R.ES	0.29±0.32	-0.05±0.46	-0.37±0.59	-1.10±0.45	48.79**	A>B>C>D
S-Ext						
L.RA	0.30±0.30	-0.05±0.44	-0.37±0.43	-0.97±0.50	48.36**	A>B>C>D
R.RA	0.35±0.34	0.01±0.44	-0.68±0.58	-1.05±0.51	53.81**	A>B>C>D
L.IO	0.40±0.45	0.10±0.25	-0.23±0.59	-1.05±0.51	9.01**	A>B>C,D
R.IO	0.34±0.40	-0.05±0.47	-0.02±0.56	-0.37±0.63	9.24**	A>B,C>D
L.ES	0.22±0.28	-0.22±0.31	-0.72±0.38	-1.34±0.50	94.69**	A>B>C>D
R.ES	0.15±0.25	-0.38±0.42	-0.91±0.57	-1.50±0.51	72.76**	A>B>C>D

Values are means±standard deviation.
S-Flex: shoulder flexion, S-Ext: shoulder extension, SD: shoulder-width double leg stance, ND: narrow base double leg stance, TS: tandem stance, SS: non-dominant single leg stance, L.RA: left rectus abdominis, R.RA: right rectus abdominis, L.IO: left internal oblique, R.IO: right internal oblique, L.ES: left erector spinae.

Table 3. Characteristics of the center of pressure according to the base of support at the right shoulder flexion and extension

	SD(A)	ND(B)	TS(C)	SS(D)	F	Post-hoc
S-Flex						
Area (mm^2)	128.85±68.53	169.13±142.31	361.50±165.14	267.45±129.71	18.90**	A,B<D<C
Length (cm)	28.42±6.34	31.23±13.39	76.09±21.86	58.36±19.07	58.82**	A,B<D<C
Ave.speed (cm/s)	0.93±0.21	1.03±0.44	2.52±0.72	2.03±0.57	66.94**	A,B<D<C
S-Ext						
Area (mm^2)	0.30±0.30	0.05±0.44	0.37±0.43	0.97±0.50	48.36**	A>B>C>D
Length (cm)	0.35±0.34	0.01±0.44	0.68±0.58	1.05±0.51	53.81**	A>B>C>D
Ave.speed (cm/s)	0.40±0.45	0.10±0.25	0.23±0.59	1.05±0.51	9.01**	A>B>C,D

Value are means±standard deviation.
S-Flex: shoulder flexion, S-Ext: shoulder extension, SD: shoulder-width double leg stance, ND: narrow base double leg stance, TS: tandem stance, SS: non-dominant single leg stance, Ave.speed: average of speed.

right erector spinae had a significant difference in each of different bases ($p < 0.05$). And both internal oblique abdominis in non-dominant single stance (SS) had not a significant difference with tandem stance (TS) but had a significant difference with the shoulder-width double leg stance (SD), narrow base double leg stance (ND). Between SS and TS had a significant difference at the left side of erector spinae. And SS and TS had each significant difference with SD, ND (Table 2).

The characteristics of COP displacement according to each different base had a significant difference in each other ($p < 0.01$). Displacement area, displacement length, the average velocity of COP is largest during TS, and these values during TS had a significant difference with the values during SS. The values of TS and SS had a significant difference with SD, ND in each other (Table 3).

2. The comparison of the onset time of postural muscle and characteristics of COP displacement according to bases during shoulder extension.

There was a significant difference in the onset time between each 4 bases which have different stability each other ($p < 0.01$).

In the post-hoc comparison result, the onset time of both rectus abdominis and erector spinae during TS were fastest and it hadn't significant difference between during TS and SS. On the other hands, the values during TS had a significant difference with the values during SD, ND each other.

The onset time of right side internal oblique abdominis during SS

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was fastest. And the onset time during SS had a difference with each other bases significantly. However, there is no significant difference in onset timing between during ND and TS (Table 2).

The characteristics of COP displacement according to each different base had a significant difference ($p < 0.01$). Displacement area, displacement length and average velocity of COP were largest during TS, and they had no significant difference with the values during SS. The values of SD and ND had a significant difference with TS and SS. But, there was no difference between SD and ND significantly (Table 3).

DISCUSSION

The postural control should satisfy both stability and mobility. Balance control reflex response which make to move the COP into the BOS appears for stabilizing a body during postural instability.[18] The balance control requires musculoskeletal control, biomechanical factor, neural process and integration of sensory information.[19] In the unstable state, postural control needs more complex process and usage of more muscles and muscle activation than in stable state.

In the previous study, during rapid upper extremity flexion movement, the contraction of postural muscle and lower extremity muscle was faster than the contraction of anterior deltoid muscle which is set the standard of muscle onset time.[5,8,20-23] The Kung, Shin and Jung[22] studied APA during active upper extremity and lower extremity movement with sitting position. In consequence of the study, contralateral internal oblique muscle and erector spinae contracted anticipatively when upper extremity flexed. Besides, when upper extremity and lower extremity moved, the onset time of contralateral postural muscle was faster than ipsilateral postural muscle. Then, in the study of the extension of the upper extremity, ipsilateral erector spinae muscle showed more delay in activation time than posterior deltoid muscle which is set the standard of muscle onset time. However contralateral erector spinae muscle and both internal oblique muscles showed more rapid onset time than the standard muscle.[8] According to these previous studies, we know that researches of the APA by the movements which are internal perturbation have been studied a lot. And we know that the contralateral postural muscle is activated faster than ipsilateral postural muscle during internal perturbation.

The significant mechanical factor which is needed for postural control is the size and characteristics of the base.[24] In the previous studies about postural control relation to the size of the bases, we know that the narrower the base, the lesser stable postural stability, and the wider the displacement area.[25] Kyung et al.[11] studied the effects of different bases on the body. And they found that as the area of bases becomes larger, the perturbation of body becomes bigger too. In other words, the narrower base induces to make more unstable posture. The larger the base, the easier it is to place the COP within the BOS. So, postural stability is increased So, postural stability is increased.[11,26] From the previous studies, we know that area size of the base is connected with postural stability. And then, we know that there were many previous studies of COP displacement characteristics or muscle onset time which reflects the APA characteristics of postural muscle.[27] But there was no study reflecting both characteristics until now. For that reason, we researched the APA characteristics (COP displacement, muscle onset time) according to various bases during internal perturbation which is upper extremity flexion and extension, in standing position. And we expected to find out APA characteristics which are more complex.

In this study, participated thirty healthy subjects. They performed shoulder flexion and extension tasks using the dominant upper extremity. The tasks were performed during the various BOS conditions which are SD, ND, TS, and SS. The onset time of postural muscle and the characteristics of the COP displacement were measured at the tasks. The onset time of postural muscle was measured by EMG, and the characteristics of COP were measured by biorescue. As the result, at the upper extremity flexion with SS position, onset times of all postural muscles excepted internal oblique abdominis were fastest compared with other position. And then, the muscle onset occurs in the following order: TS, ND, and SD. In the previous study, at the upper extremity flexion with SD, external oblique abdominis was not activated anticipatively, but internal oblique abdominis was activated anticipatively. But in this study, there was no anticipative activation in all of the muscles with SD. On the other side, during TS and SS, there was anticipative activation in all muscles measured.

In the other previous study which measured the pelvic-width double leg stance during upper extremity extension, the onset time of ipsilateral erector spinae muscle was delayed but contralateral internal oblique abdominis was activated anticipatively. In upper ex-

tremity extension of this study, the onset time of postural muscle was the fastest in SS. And then, the activation time was in the following order: TS, ND, and SD. This result is the same with the upper extremity flexion. In the SD with upper extremity extension, there was no anticipatory muscle activation in all postural muscles measured. But, in the ND, there were anticipative activations in left side rectus abdominis, right side internal oblique abdominis and both erector spinae muscle. And, in the TD and SS, there were anticipative activations in all postural muscles measured. So, we knew that the more the base is unstable, the more the onset time of postural muscle is fast. This means that the more unstable movement is expected, the more rapid APA mechanism is activated. In a comparison to the onset time of right postural muscles which is ipsilateral side and the onset time of left postural muscles which is contralateral side, at the TD and SS, onset time of left postural muscles were faster than right postural muscles. This result coincides with the previous study.[22] The result explains that contralateral postural muscle affects postural control more than ipsilateral postural muscle during upper extremity movements.[16]

The displacement characteristics of the COP was changed according to various bases. In the upper extremity flexion, the COP displacement area, displacement length and average velocity showed bigger values in SS than SD, ND. And the biggest values appeared in the TS. There was a significant difference between the final values. In the previous study, they found that the more the BOS was narrowed, the more the COP displacement velocity was increased and the more maintaining time in the base was reduced. This means that the more the base is narrowed, the more the postural stability is decreased. It is the strategy increasing body degree of freedom compensately.[28] In the SS position, they use the dominant side foot for compensatory strategy against postural perturbation. So, the result values which is the displacement area of COP, displacement length, and average velocity at the SS position are lower than the values at the TS position. TD position requires feet on the base so their degree of freedom was limited. In the upper extremity extension, TD had the bigger values but there wasn't a significant difference between the result of TD and SS.

The upper extremity flexion with SS makes to move the upper extremity's COM toward the anterior direction and it makes to move the lower extremity's COM toward the posterior direction. So, the COP displacement of the trunk is balanced well. But the upper extremity extension with SS makes to move the COP of upper extremity and lower extremity toward a posterior direction. Then it makes the compensatory COP displacement of trunk toward an anterior direction. Because of it, the result, which is the upper extremity extension with SS has bigger COP displacement than the upper extremity flexion with SS, can be explained.

This study is about the characteristics of APA due to the difference bases. The study showed that narrower bases threaten the physical balance and stability, and we can find out the appearance of more rapid anticipatory postural control in contralateral postural muscle when performing the movement of the upper extremity. So, we think that these characteristics according to the BOS which is based on this study can widely use at the processing of treatment of the patients having problems about APA. But, the task of this study does not have a goal. So, we think that this task can't perfectly reflect the characteristics of APA while performing activities of daily living (ADL). We think that in future it needs additional studies of APA according to characteristics of bases referring to the ADL.

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