Method for obtaining quantitative change in muscle activities by difference in sensory inputs about human posture control

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Abstract: Human posture control is a very complicated mechanism integrating multi-inputs and outputting correct motion. In this research, we propose a method to obtain quantitative changes in muscular activity caused by changing sensory inputs assuming that muscle activity is divided into external force elements and modality elements, and we propose that the this method is a viable means for determining the validity of this idea and calculating quantitative changes in muscular activity.

Keywords: mobiligence, human posture control, standing posture, muscle activity

1. INTRODUCTION

Humans control their posture by controlling the muscle activity of the whole body with the cranial nervous system using multi-sensory inputs. The construction of sensory inputs and muscular activity model has a significant meaning medically and biologically because this model more clearly elucidates the brain functions. Thus, examining the relationship between senses and muscular activity is important as the first step in constructing this model.

In former studies, the human posture control was researched by Nashner[1] and Bottaro[2]. In these studies, however, changes in muscular activity that resulted from changing sensory inputs were an unknown. Therefore, this paper proposes a method to obtain quantitative changes in muscular activity caused by changing sensory inputs.

To achieve this purpose two challenging points exist: i)the method of changing sensory inputs and ii)the quantification of changes in muscular activity by sensory inputs. Regarding the method, we propose a method of changing sensory inputs by inhibiting or stimulating three sensory systems (visual, vestibular and somatosensory) which are considered closely related to posture control. Regarding the quantification, muscle activity changes seem to occur when an external force is applied to the body causing posture changes. Thus, we propose a method to estimate changes in muscular activity by external force and exclude them.

In this study, maintaining a standing posture is targeted due to measuring changes in muscular activity by sensory inputs because it is a simple movement limited to changes in muscular activity. In addition, physically-healthy persons are targeted because how the brain functions may differ from those of physically-challenged.

2. PROPOSED METHODS

It is assumed that the muscular activity of posture control is expressed in elements changed by external forces and elements as indicated by the sensory inputs, making the following formula applicable:

$$A_{ctivity\_i} = \mathrm{f}_i(\boldsymbol{F}_{orce}) + \mathrm{g}_i(\boldsymbol{M}_{odality})$$
$$i = 1, 2, \cdots, \mathrm{n}$$

$A_{ctivity\_i}$ is scalar of the *i*th muscular activity. $\boldsymbol{F}_{orce}$ is a vector meaning the external force applied to the body. $\boldsymbol{M}_{odality}$ is a vector meaning the sensory inputs condition.

The method for obtaining $\mathrm{g}_i(\boldsymbol{M}_{odality})$ is described. $\mathrm{f}_i(\boldsymbol{F}_{orce})$ is calculated from the model constructed by measuring electromyogram (EMG) of subject's muscles in various postures. $A_{ctivity\_i}$ is obtained by measuring EMG of subject's muscles when subject's senses are inhibited or stimulated. $\mathrm{g}_i(\boldsymbol{M}_{odality})$ is calculated as the difference between $A_{ctivity\_i}$ and $\mathrm{f}_i(\boldsymbol{F}_{orce})$. Figure 1 shows the outline of this method.

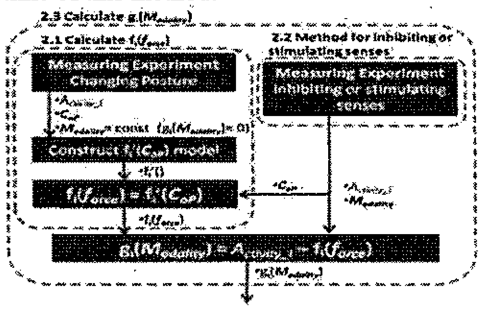

Fig. 1 Method Outline

2.1 Calculate $\mathrm{f}_i(\boldsymbol{F}_{orce})$

In maintaining a standing posture, posture and external forces are assumed to be unique provided the Center of Pressure (CoP) position is uniquely decided. In this study, $\boldsymbol{C}_{oP}$ is defined as a vector meaning CoP position and $\mathrm{f}_i(\boldsymbol{F}_{orce})$ is considered equal to $\mathrm{f}_i'(\boldsymbol{C}_{oP})$ for easily understanding changes in muscular activity by external force. Thus, $\mathrm{f}_i(\boldsymbol{F}_{orce})$ is calculated from $\mathrm{f}_i'()$ and $\boldsymbol{C}_{oP}$.

Experiments are performed to measure $\boldsymbol{C}_{oP}$ and $A_{ctivity\_i}$ when a subject's senses are uninhibited or not stimulated and subject leans to the front or back, to the left or right, and any combination thereof. The weight shift values using four scales are used to determine $\boldsymbol{C}_{oP}$. The EMG of each muscle are used to determine $A_{ctivity\_i}$. Three-dimensional models of $\mathrm{f}_i'()$ are constructed with planes calculated from all three points composing measured $\boldsymbol{C}_{oP}$ and $A_{ctivity\_i}$. $\mathrm{f}_i(\boldsymbol{F}_{orce})$ in arbitrary posture can then be calculated.

2.2 Method for inhibiting or stimulating senses

Sensory inputs from visual, vestibular, and somatosensory systems are considered: the visual sense is inhibited by closed eyes, the vestibular sense is inhibited by a caloric test that upset the vestibular system by pouring cold water into the ear cavity, and the somatosensory sense is stimulated by touching a part of the body. If these senses are inhibited or stimulated, subjects tend to change their posture.

- If only the vestibular sense is inhibited, subject can maintain the standing posture (Fig. 2A).
- If both visual and vestibular senses are inhibited simultaneously, subject leans (Fig. 2B).
- If both visual and vestibular senses are inhibited and somatosensory sense is stimulated, subject recovers its standing posture (Fig. 2C).

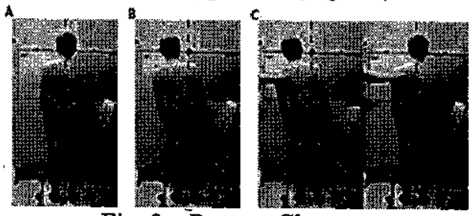

Fig. 2 Posture Change

2.3 Calculate $g_i(M_{odality})$

Experiments easure C_{oP} and $A_{ctivity\_i}$ and $M_{odality}$ when subject's senses are inhibited or stimulated by the method described inm paragraph 2.2. $M_{odality}$ is recorded for the eight combinations of the three sensory systems. Then $f_i(F_{orce})$ is calculated from C_{oP} by the method described in paragraph 2.1. $g_i(M_{odality})$ can be calculated as the difference between $A_{ctivity\_i}$ and calculated $f_i(F_{orce})$.

3. EXPERIMENT

3.1 Experiment Conditions

Subject is one male in his twenties. Figure 3 shows muscles measured in experiments.

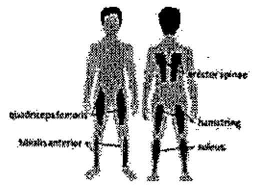

Fig. 3 Measured Muscles

3.2 Results

Figure 4 shows calculated f_i'() of each muscle. The x-y plane means C_{oP}. $g_i(M_{odality})$ were calculated and investigated by an analysis of variance (ANOVA) to evaluate contribution ratio of each element of Modality in $g_i(M_{odality})$ as shown in Table 1. *A* is visual factor; *B* is vestibular factor; *C* is somatosensory factor; and A×B, A×C, and B×C are interactions with each factor. The value is the variance ratio. A higher value means that $g_i(M_{odality})$ is more affected by that factor. If there is 0.05 or 0.01 level of statistical significance in the factor, probability p<0.05 (*) or p<0.01 (**) is added. The item of the sign ○ shows variance ratio is 1.0 or less, within the range of error.

3.3 Discussion

The existence of threshold is considered from Figure 4, especially in y of tibialis anterior. Three-dimensional models of f_i'() constructed with planes composed partially is considered more precise than with the plane composed of the whole.

Concerning the validity of the assumption about the muscular activity, if $f_i(F_{orce})$ and $g_i(M_{odality})$ are changed by F_{orce} and $M_{odality}$, then elements of the muscular activity are considered valid. Figure 4 shows that $f_i'(C_{oP})$ is not constant but changes according to C_{oP}. This means that $f_i(F_{orce})$ changes when F_{orce} changes. Moreover, significant differences can be found in Table 1. This means that $g_i(M_{odality})$ changes by $M_{odality}$. Therefore, we believe that this assumption is valid. The changes in muscle activity are obtained as $f_i(F_{orce})$ and $g_i(M_{odality})$ when the proposed method is used.

Table 1 shows that the factors affecting $g_i(M_{odality})$ differ respectively, which also indicates that some muscles are influenced by one sense, two or more senses, and even the interaction of senses.

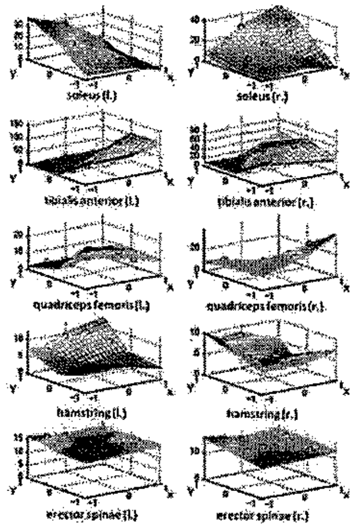

Fig. 4 Calculated $f_i'(C_{oP})$ for Each Muscle

Table 1 ANOVA Results

F value	A	B	C	A×B	A×C	B×C
soleus (l.)	1.85	123.26**	○	○	1.46	15.64**
soleus (r.)	12.94**	211.73**	10.62**	○	1.97	8.77*
tibialis anterior (l.)	○	154.45**	5.22*	○	7.42*	○
tibialis anterior (r.)	○	43.75**	○	○	4.66	1.41
quadriceps femoris (l.)	○	36.71**	○	○	○	3.09
quadriceps femoris (r.)	1.91	88.65**	1.57	1.50	5.58*	○
hamstring (l.)	2.93	○	1.72	○	○	○
hamstring (r.)	○	3.10*	1.86	9.19*	○	○
erector spinae (l.)	5.76*	172.53**	6.26*	6.77*	15.00**	9.38*
erector spinae (r.)	○	73.02**	2.79	4.61*	9.42*	3.73

A: visual, *B*: vestibular, *C*: somatosensory
* : p<0.05, **: p<0.001, ○: pooling into error term

4. CONCLUSIONS

This paper proposes a method for obtaining quantitative change in muscle activity caused by changes in sensory input conditions. This method was founded on the assumption that muscular activities were divided into external force elements and modality elements. Results of investigating whether this assumption was valid proved that this assumption was actually valid, and this method was a viable means for obtaining quantitative changes in muscular activity.

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