Muscle Activities Changing Model by Difference in Sensory Inputs on Human Posture Control

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Abstract. For understanding of human posture control, changes in muscular activity caused by changes in sensory inputs are very important because the control mechanism is complicated with integrating multi-inputs and outputting various and simultaneous muscular activity. In this research, we aim to obtain quantitative changes in muscular activity caused by changes in sensory inputs. For this purpose, we propose a method to be founded on the idea that muscle activity is divided into external force elements and internal elements. With this method, we can show the existence of internal muscular activity as well as external muscular activity. And it is considered that new model of human posture control with the difference of sensory inputs might be obtained.

Keywords: mobiligence, human posture control, multi modality, muscle activity.

1 Introduction

Humans control their posture well 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 leads us to understand how the brain functions. Thus, it is important to examine the relationship between senses and muscular activity as the first steps 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 changes with sensory inputs integration were not discussed clearly.

In other some resources, the posture controls with the different sensory inputs are modeled in focus on torque controls at each joint. Peterka[3] propose the posture

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control model with PID control for understanding of influences between the sensory inputs and torque outputs (see Fig.1). In this paper, the influences of sensory inputs are just summed with certain weights at an integrator. Therefore they consider the influences of sensory inputs independently. Kooij[4] propose the posture control model with Kalman filter for the estimation of sensory noise and human state based on their previous work[5].

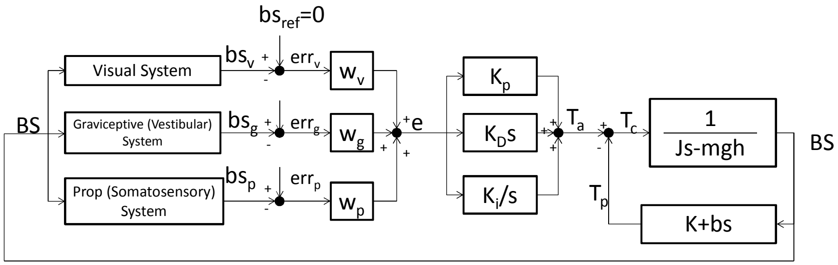

Fig. 1. "Independent channel" model of sensory integration in postural control showing a weighted addition of contributions from visual, proprioceptive, and graviceptive systems to the generation of an active corrective torque, T_a, as well as a passive torque contribution, T_p, related to body movement relative to the feet[3].

In these previous researches, the outputs are considered as torque of each joint. However, it is considered that human control not torque but muscular activity connected to neurons in spinal cord. The posture might be controlled from sensory inputs to muscular activity through many neurons. The muscular activities are various in the same torque because of the existence of flexor and extensor muscles. In other words, torque at each joint makes "external force" for the human posture directly, and the muscular activity makes not only "external force" but also "internal force" such as stiffness at each joint. In the same posture, the outputs of the posture control may be different because of the existence of the "internal force" with the difference of sensory inputs.

For example, a person with Parkinson's disease makes action with high muscle tonus but the changes of their posture is very small with very low torque. It can be considered that they make "very high internal force" and "very low external force".

Therefore, this paper proposes a method to obtain quantitative changes in muscular activity caused by changes in sensory inputs. From the understandings of quantitative changes in muscular activity, the internal force by the changes of sensory inputs may be found.

To achieve this purpose two challenging points exist:

i) How to change sensory inputs with the changes of muscular outputs
ii) How to obtain the quantitative "internal" muscular activity without "external" muscular activity

Regarding the changes of the sensory inputs, we propose the method of changing sensory inputs by inhibiting or stimulating three senses (visual sense, vestibular sense and somatosensory sense) which are considered closely related to posture control[3],[4]. Regarding the internal muscular activity, 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 the how the brain functions may differ from that of those who are physically-challenged.

2 Proposed Method

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 as the internal force, making the following formula applicable:

$$\mathrm{g}_i(Condition_j) = Activity_{ij} - \mathrm{f}_i(CoP_j) \qquad (1)$$
$$i = 1, \dots, \mathrm{n} \qquad j = 1, \dots, \mathrm{m}$$

where $Activity_{ij}$ is scalar of the ith muscular activity in the condition j and $\mathrm{f}_i(CoP_j)$ are the ith muscular activity with “normal sensory input” in the condition j. The condition is the variety of the changes of the sensory inputs mentioned later.

CoP_j is a variable to indicate the center of pressure of human body instead of the human posture. Therefore, $\mathrm{f}_i(CoP_j)$ can be considered as the muscular activity for “external force” to maintain the posture. From the above formula, $\mathrm{g}_i(Condition_j)$ can be considered as muscular activity for “internal force”. $Condition_j$ is vector meaning the sensory inputs in the jth condition. If any sense is normal, with no inhibition and stimulation, $\mathrm{g}_i(Condition_j)$ will be 0 because $Activity_{ij}$ equals to $\mathrm{f}_i(CoP_j)$. The n is the number of muscles to be measured and the m is the number of conditions with the changes of sensory inputs.

The method for obtaining $\mathrm{g}_i(Condition_j)$ is described. $\mathrm{f}_i(CoP_j)$ is calculated from the model constructed by measuring EMG of subject's muscles in various postures with the normal sensory inputs. $Activity_{ij}$ is obtained by measuring EMG of subject's muscles when subject's senses are inhibited and/or stimulated. $\mathrm{g}_i(Condition_j)$ is calculated as the difference between measured Activityij and modeled $\mathrm{f}_i(CoP_j)$. Figure 2 shows the outline of this method (see chart in next page).

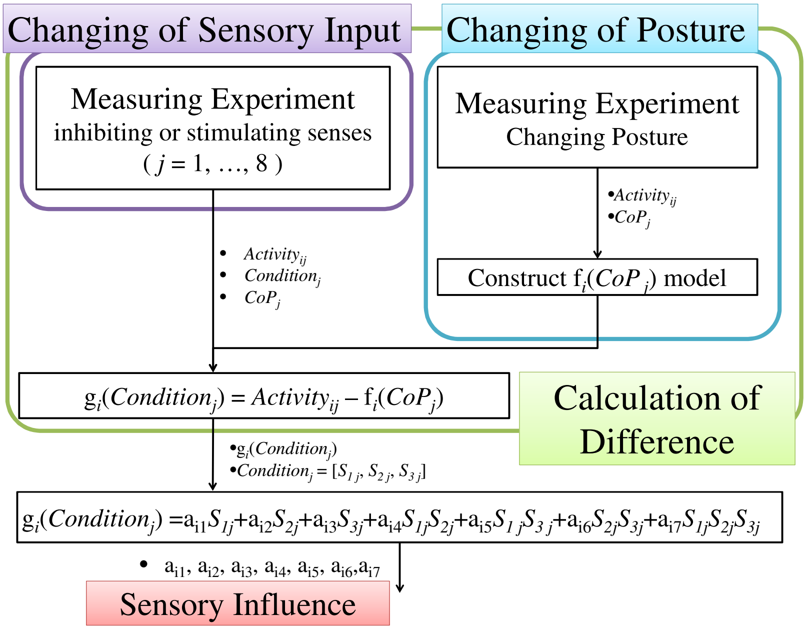

Fig. 2. Outline of proposed method

2.1 Calculation of Muscular Activity for External Force

In maintaining a standing posture, posture and external forces are considered uniquely decided provided the Center of Pressure (CoP) position is uniquely decided. In this study, CoP_j is defined as vector meaning CoP position and it is considered that the external force is $f_i(CoP_j)$.

Experiments were performed to measure CoP_j and $Activity_{ij}$ when any subject's sense is uninhibited or not stimulated; that is, $g_i(Condition_j) = 0$, and subject leans to the front or back, to the left or right, and any combination thereof. CoP is measured by four scales and calculated. $Activity_{ij}$ is measured as EMG of each muscle and calculated. The model of f( ) is constructed with measured CoP and $Activity_{ij}$.

In concrete, for the construction of this model, the subjects are measured the muscular activities at 9 points to change their posture. And then, the muscular activities of 16 points are estimated with the average of the neighbor activities. Finally, we make meshes based on the measured points and estimated points. Figure 3 shows these points where x is right side and y is front side. The measured points may need to increase for the precise estimation. However, the number of the points is set 9 of the minimal value because we consider the subjects' exhaustion.

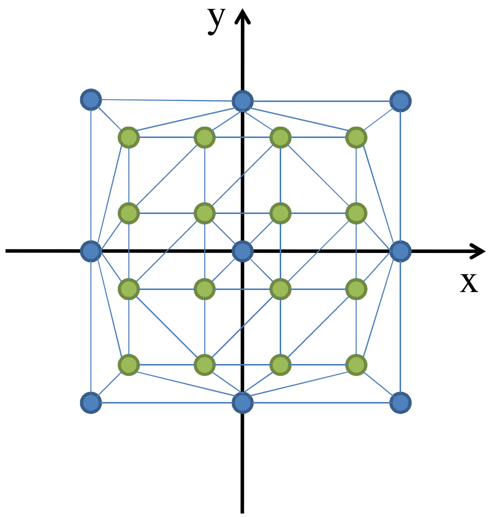

Fig. 3. Measured and estimation points for $f_i(CoP_j)$ model. Blue points indicate the measured points and green points indicate the estimated points.

2.2 Calculation of Muscular Activity for Internal Force

The internal force elements $g_i(Condition_j)$ can be obtained from muscular activities and external force elements mentioned above.

And for the estimation of influence of sensory inputs, we calculate the coefficients of the input factors. As mentioned later, we set 8 conditions corresponding to 3 sensory inputs. Each sensor is inhibited or stimulated and combined them in our experiments.

Therefore, the influence of each sensory input and these combinations can be obtained with the below formula.

$$g_i(Condition_j) = a_{i1}S_{1j} + a_{i2}S_{2j} + a_{i3}S_{3j} + a_{i4}S_{1j}S_{2j} + a_{i5}S_{1j}S_{3j} + a_{i6}S_{2j}S_{3j} + a_{i7}S_{1j}S_{2j}S_{3j} \quad (2)$$

where S_{1j} indicate the sensory condition j in sensor1 (visual). S_{2j} indicate the sensory condition j in sensor2 (vestibular). S_{3j} indicate the sensory condition j in sensor3 (somatosensory).

So, we can obtain the a_1, a_2, a_3, a_4, a_5, a_6 and a_7 from the value of $g_i(Condition_j)$ with 8 kinds of conditions.

2.3 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. 4(a)).
- If both visual and vestibular senses are inhibited simultaneously, subject leans to the same side of inhibited ear (Fig. 4(b)).
- If both visual and vestibular senses are inhibited and somatosensory sense is stimulated simultaneously, subject recovers its standing posture (Fig. 4(c)).

The interesting thing is that the side of the leaning depends on the side of inhibited vestibular sense, but the touching point for the stimulated somatosensory sense is independent to recover their posture. Now, we have not verified and made the consideration the reasons. We will try to model this fact in the future work.

From these changes of the posture with the changes of sensory inputs, we can provide 8 conditions with different sensory inputs. $Condition_1$ is the normal posture and $Condition_{2\text{-}7}$ are the inhibitions and/or stimulation of the 3 sensory inputs. Table 1 shows the combinations of these sensory inputs as conditions. Table 2 shows the S_{1j}, S_{2j}, S_{3j} values in each condition. The $g_i(Condition_j)$ can be obtained from these 8 conditions experiments and $a_{1\text{-}7}$ can be obtained the $g_i(Condition_j)$ and the S_{1j}, S_{2j}, S_{3j} values in each conditions.

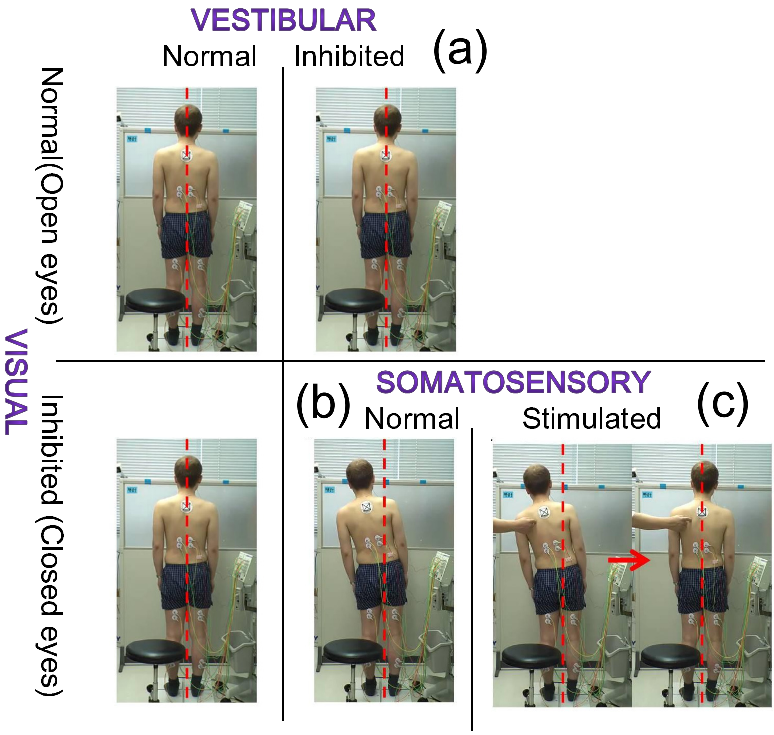

Fig. 4. Posture Change

Table 1. Conditions of sensor changings

(n : normal, i : inhibited, s : stimulated)

Conditions	1	2	3	4	5	6	7	8
Visual (S1)	n	i	n	i	n	i	n	i
Vestibular (S2)	n	n	n	n	i	i	i	i
Somatosensory (S3)	n	n	s	s	n	n	s	s

Table 2. Values of S_{1j}, S_{2j}, S_{3j}

Condition	1	2	3	4	5	6	7	8
S_{1j}	0	1	0	1	0	1	0	1
S_{2j}	0	0	0	0	1	1	1	1
S_{3j}	0	0	1	1	0	0	1	1

3 Experiment

3.1 Experimental Conditions

Subjects are 12 males in their twenties. Figure 5 shows muscles measured in experiments. We carry out the measurements of these muscles in the experiment for external for elements ($f_i(CoP_j)$) and in every 8 conditions. And then, we calculate the internal force element ($g_i(Condition_j)$) from muscular activities in 8conditions and the external force elements.

The visual inhibitions are achieved with "close eyes" and the vestibular inhibitions are achieved with pouring cold water "to left ear". The somatosensory stimulations are achieved with touching at "any point on the surface of his body".

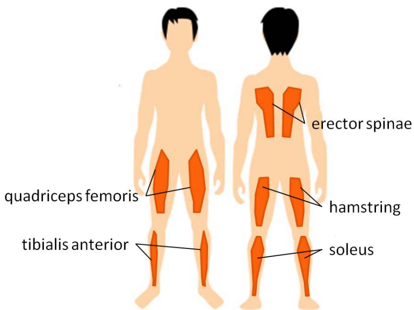

Fig. 5. Measured muscles

3.2 Experimental Results and Discussion

3.2.1 External Force Elements Model

At first, we show the results of the model for the representation of relationship between muscular activity and the center of pressure in order to model the external force elements.

For these models, we carry out the experiments in which subject change his posture to be 9 points of center of pressure. Those are front, front-right, front-left, center, center-right, center-left, back, back-right and back-left.

Figure 6 shows the model of each muscle. (l.) means the left side of body and (r.) means the right side. In these graphs, x axis indicates the right and left side (x plus is right), and y axis indicates the front and back side (y plus is front). And z axis indicates the muscular activity. In these graphs, it can be seen that circle points which

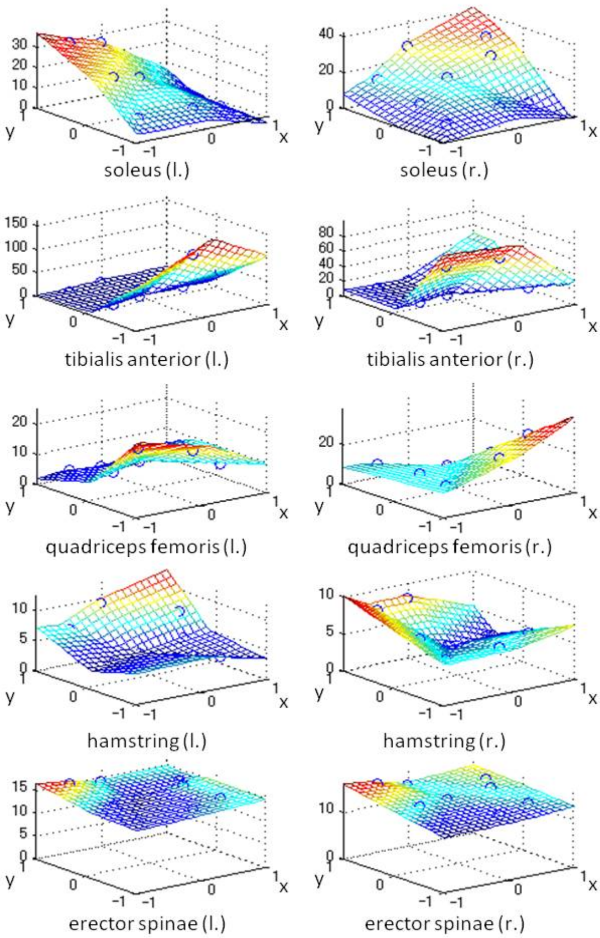

Fig. 6. Modeled external force element activity for each muscle

are the measured points. And then, we construct the model based on these measured muscular activities.

As the results, it can be seen that the activity of left side soleus increases when the CoP is front-left. On the other hand, the activity of right side soleus increases when the CoP is front-right. It is considered that these are very natural because soleus should work when human bends his body to front and keep the posture.

3.2.2 Internal Force Element Calculation

From the model of external force element mentioned above, the $f_i(CoP_j)$ can be obtained. In concrete, the experiments of 8 conditions might make the human posture change and the CoP might be changed. Therefore, using the CoP data, the external force element remove from the muscular activities. The result should be the muscular activities of the internal force elements by the changes of sensory inputs.

Table 3 shows the results of muscular activities of each muscle i in each condition j. Condition_1 is normal condition that is no inhibition and no stimulation. Therefore, the muscular activities are all 1.0 as the control data. The other activities are normalized based on this control data.

Table 4 shows the results of muscular activities for "internal force elements" of each muscle i in each condition j. These values are calculated based on the formula (1). Figure 7 shows the difference of the center of pressure in each condition. It can be seen that the CoP are various because the postures are various in the experiments. Therefore, for obtaining the "internal force element", $f_i(CoP_j)$ plays very important role.

In both tables, high values are painted red and low values are painted blue. It can be seen that both $Activity_{ij}$ and $g_i(Condition_j)$ are very high from condition5 to condition8. This result is very natural because human makes his body "hard" when sensory inputs, especially vestibular, are inhibited and not stimulated. In condition6, subjects lean their body and their all muscular activities are also high.

Table 3. Muscular activities in 8 conditions ($Activity_{ij}$)

conditions	1	2	3	4	5	6	7	8
soleus (left)	1.00	1.19	1.18	1.34	1.38	1.71	1.40	1.84
soleus (right)	1.00	1.12	1.11	1.21	1.29	1.48	1.32	1.60
tibialis anterior(l)	1.00	1.26	1.40	1.33	2.29	4.51	2.47	4.41
tibialis anterior(r)	1.00	1.29	1.25	1.23	2.35	4.44	2.15	4.33
quadriceps femoris(l)	1.00	1.16	1.21	1.20	1.64	3.61	1.91	4.49
quadriceps femoris(r)	1.00	0.91	0.90	1.10	1.88	2.81	1.93	3.35
hamstring(l)	1.00	1.44	1.64	1.68	1.44	1.75	1.62	1.94
hamstring(r)	1.00	1.38	1.39	1.60	1.38	1.64	1.47	1.64
erector spinae(l)	1.00	1.03	1.04	1.05	1.12	1.16	1.14	1.23
erector spinae(r)	1.00	1.02	1.01	1.04	1.15	1.21	1.15	1.26

Table 4. Muscular activities of internal force elements in 8 conditions ($g_i(Condition_j)$)

conditions	1	2	3	4	5	6	7	8
soleus (left)	-0.04	0.01	-0.01	-0.01	0.21	0.47	0.17	0.51
soleus (right)	-0.06	-0.11	-0.06	-0.03	0.17	0.42	0.13	0.40
tibialis anterior(l)	-0.31	-0.39	-0.18	-0.21	0.64	2.63	0.78	2.72
tibialis anterior(r)	-0.37	-0.49	-0.49	-0.5	0.68	2.67	0.54	2.67
quadriceps femoris(l)	-0.24	-0.33	-0.21	-0.18	0.19	1.94	0.48	2.96
quadriceps femoris(r)	-0.2	-0.54	-0.51	-0.23	0.44	1.18	0.43	1.82
hamstring(l)	-0.23	0.005	0.184	0.15	0.13	0.41	0.17	0.54
hamstring(r)	-0.15	0.053	0.096	0.213	0.02	0.27	-0.03	0.20
erector spinae(l)	-0.04	-0.08	-0.13	-0.13	-0.06	0.02	-0.02	0.06
erector spinae(r)	-0.04	-0.09	-0.18	-0.15	-0.06	0.03	-0.03	0.07

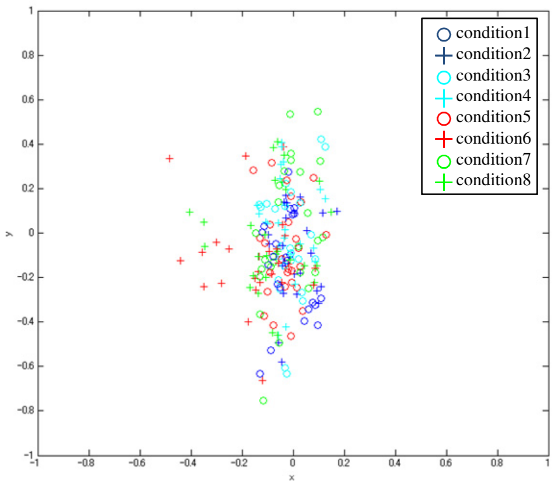

Fig. 7. Center of pressure in each condition

3.2.3 Influence of Sensory Inputs

From the calculation of $g_i(Condition_j)$ mentioned above, the influences of the sensory inputs to the internal force element activities can be obtained based on the formula (2).

Figure 8 shows the results of $a_{1\text{-}7}$. The coefficients has the meanings that a_1 is only visual influence, a_2 is only vestibular influence, a_3 is only somatosensory influence, a_4 is the combination influence of visual and vestibular, a_5 is the combination influence of visual and somatosensory, a_6 is the combination influence of vestibular and somatosensory and a_7 is the combination influence of visual, vestibular and somatosensory.

Form the result of Fig.8, it is clear that a_4 is significantly high regarding the error. That is to say, human makes their body "hard" in the situation that both visual and vestibular systems are inhibited(a_4). However, in such a situation, with the stimulation of the somatosensory system, their posture control works well.

From this result, it can be considered that "internal force elements" exist on the human posture control by the changes of sensory inputs. Moreover, we can find that the sensory inputs are integrated and utilized in human posture control. The sensory inputs cannot be considered independently. Therefore, we think that multi-modality should be more considered.

These results are the average of subjects in which there are several individual differences. However, there are obvious means statistically. Therefore, we think these results are general.

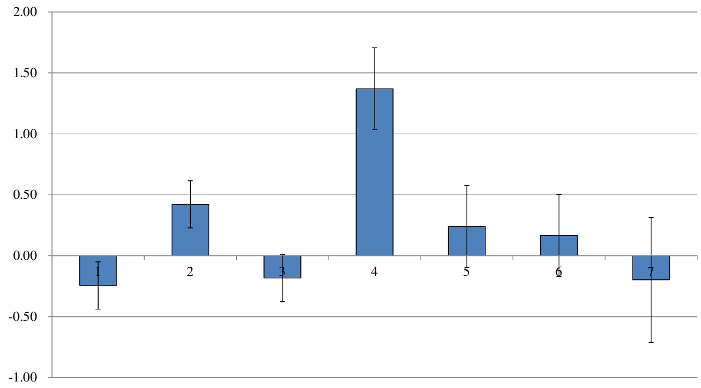

Fig. 8. Influence of each sensory input and these combinations ($a_{1\text{-}7}$)

3.3 Discussion of Model

From the results in this paper, we may be able to consider a new model of human posture control.

In the torque based human posture control, both flexor and extensor muscles make only "external force (torque)" on the joint (Fig.9). However, in this paper, we suggest that the existence of "internal force ($g_i(Condition_j)$)" by the difference of the sensory inputs. At the same time, the sensory inputs do not independently work but work with the integration.

Therefore, we extend the posture control model the previous work. Figure 10 shows the new posture control model. In this model, the flexor and extensor muscles are controlled by both external output and internal output. About the external output, Peterka's model[3] can be applied. Internal elements should be driven by sensory integrator. However, that is not still understood well how to control the internal force elements.

In the dangerous situation such as 2 or more sensory inputs inhibition, it is very natural to make the high body stiffness. It is very importance that the existence is found. In previous studies, only torque calculation is focused on. Our contribution is the findings of the fact that not only torque but also joint stiffness and viscosity should be considered in the modal.

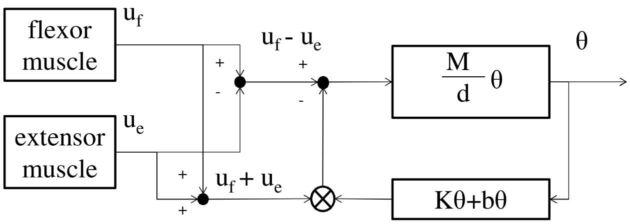

Fig. 9. Model of previous work (Torque based) [6]

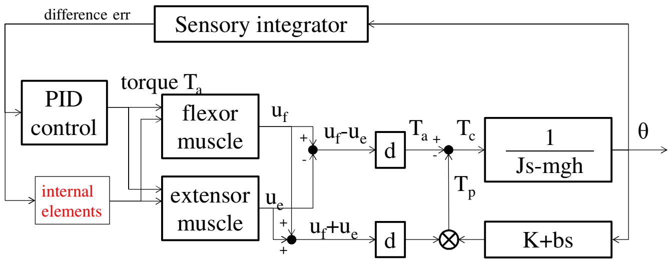

Fig. 10. Model of this work (Muscular Activity based)

4 Conclusion

This paper proposed a method to obtain quantitative changes in muscle activity caused by changes in sensory input conditions. With this method, we can show the existence of internal force elements as well as external force elements. The sensory inputs are integrated in human posture control as multi-modality.

Form the results, the new model of human posture control is suggested. The internal elements are driven by the sensory integrator and these make the human body stiffness.

As the future work, we firstly consider the control model of internal force element. And the sensory inputs integrator is also important for the understandings of human posture control. For these works, we will carry out more experiments and to measure how to work the brain in the experiments with NIRS.

In this study, the posture can be measured by the center of pressure. However, we can measure more certain posture with motion capture systems.

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