INTRINSIC VISCOELASTICITY OF ANKLE JOINT DURING STANDING

K.Fujita* and H.Sato*

*Department of Computer and Information Science, Iwate University

*E-mail: fujita@cis.iwate-u.ac.jp

ABSTRACT

The ankle joint intrinsic viscoelasticity of standing human was measured using a newly developed system which allows to apply rapid mechanical perturbation to the ankle joint. The viscoelasticity without the contamination of the stretch reflex was identified using the response during first 50 millisecond of the measured step response.

The measured elasticity values in 10 normal subjects were 30 Nm/rad in sitting, 95 Nm/rad in standing and 212 Nm/rad in single-leg standing. The functional role of the intrinsic viscoelasticity in postural stability was estimated as about 32%.

The eyes-closed standing also showed significant increase of viscoelasticity during normal (121 Nm/rad) and single-leg standing (241 Nm/rad). It strongly suggests the existence of a higher postural control system which modulates the intrinsic viscoelasticity with the environment.

INTRODUCTION

The component to determine human postural stability is not only the feedback postural control system but also the stretch reflex and the joint viscoelasticity. All of these three components affects the property between the ankle joint angle and the disturbance torque. The measurement of these individual components could give more detailed information about the postural control system, however, it has not been done.

It had been shown that the viscoelasticity changes with the muscle activity, in lying subjects by Weiss et.al.[1]. The increase of the elasticity was demonstrated clearly. A continuous pseudo-random perturbation was used in that study. The elicited stretch reflex could be included in the estimated viscoelasticity. The improved identification technique had been applied recently, and the reflex stiffness was estimated as well as intrinsic stiffness in lying subject[2]. An electrical stimulation to Commonperoneal nerve was used to suppress the Soleus stretch reflex by Sinkjaer et.al.[3]. The measurement was performed during sitting and the viscosity has not been shown. Ishida et.al. developed a system using rapid disturbance to estimate the intrinsic viscoelasticity before the stretch reflex occurs[4]. The values obtained by their system could not be compared with the previous studies because they used a cascade viscoelasticity model instead of a parallel model.

In this study, we developed a system which allows to apply rapid mechanical perturbation to the ankle joint of a standing subject. The measured intrinsic viscoelasticity was compared with the previous studies, and the effect of the visual or postural environment were discussed.

METHOD

The principal idea to measure intrinsic viscoelasticity was to identify the stiffness with the response before the stretch reflex is elicited. A tilting stage was position servo-controlled with 500W DC motor as shown in figure 1. The ankle joint angle was measured with the potentiometer attached on the joint, and the reaction force was measured with four loadcells (two for horizontal and two for vertical). The acquired step

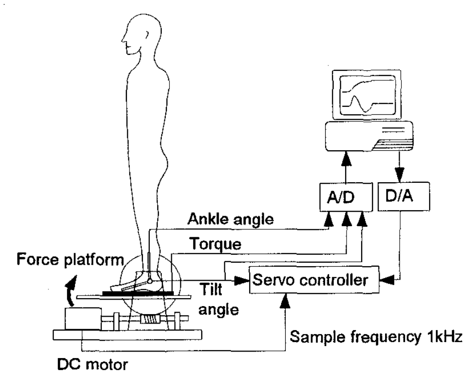

Figure 1. Experimental set-up of ankle viscoelasticity measurement system.

0-7803-5164-9/98/$10.00 © 1998 IEEE

response was stored in a PC at 1000 Hz sample frequency. An example data is shown in figure 2. The first 50 millisecond response was used to estimate the intrinsic viscoelasticity. It can be confirmed that the Soleus reflex occurs after the estimation period in figure 2(c). The viscoelasticity was identified by recursive seeking of the parameter set which provides minimum simulation error. This is called Output-Error-Minimum method. The good coincidence between the measured and the simulated ankle joint angle can be seen in figure (a).

The feet were positioned in parallel with 200mm distance, and fixed on the stage with straps. The experiment was performed in 10 normal subjects.

RESULTS AND DISCUSSIONS

The system reliability was examined by comparing the measured value with the preceding studies. The average of measured elasticity of sitting subject was 30 Nm/rad, as shown in figure 3. The value is smaller than 50Nm/rad reported by the preceding study including reflex[1], and coincides with 23~50 Nm/rad reported by the study excluding reflex[2]. The identification of intrinsic viscoelasticity was performed successively.

The elasticity during standing was 95 Nm/rad and 212 Nm/rad in single-leg standing. The elasticity in single-leg standing is about twice of it during standing, while the viscosity increases just about 50%. Weiss et. al. reported elasticity increase in proportional to the muscle activity and viscosity in proportional to the square root of the activity, but the values included the measurement with the stretch reflex [1]. The estimated intrinsic values during standing and single-leg standing supported the preceding result.

Regarding to the postural stability, an inverted pendulum model was introduced. From a viewpoint of control theory, an inverted pendulum with 60Kg mass at 1m height requires elasticity of 300Nm/rad to be stabilized. However, the measured elasticity (95Nm.rad) is obviously smaller than it. Therefore, the insufficient elasticity must be compensated by the stretch reflex and the feedback postural control system. According to this pendulum model, the functional role of the intrinsic elasticity in postural stability was estimated 32% in

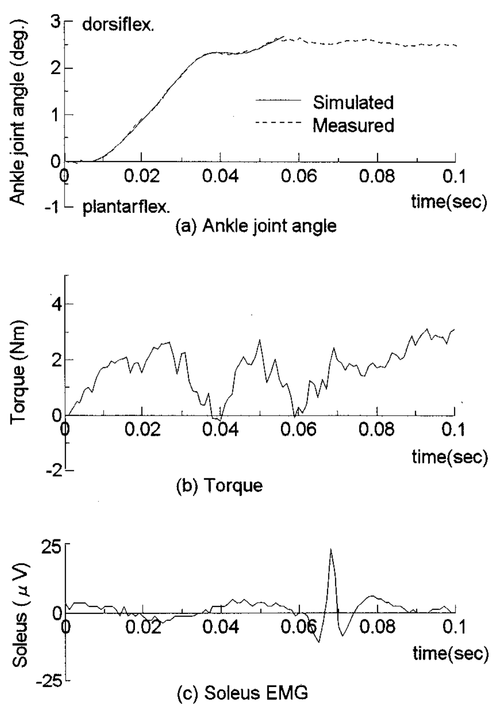

Figure 2. Property change in the supinator muscle due to the interaction with the extensor carpi radialis brevis/longs.

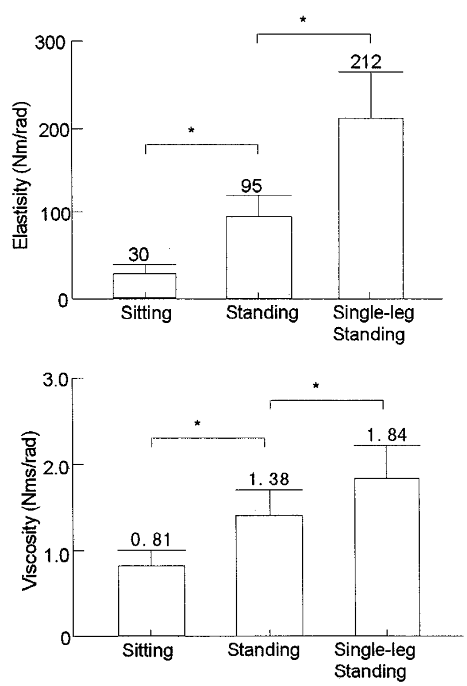

Figure 3. Viscoelasticity during sitting, standing and single-leg standing. (*: p<0.005).

standing and 35% in single-leg standing. The increase of the role in single-leg standing might suggest the existence of a higher postural control system which modulates the intrinsic viscoelasticity, stretch reflex gain and feedback postural control gain.

The elasticity measured during eyes-closed standing also showed significant increase of the viscoelasticity during normal Nm/rad and single-leg standing, as shown figure 4. The increase appears to show the complementary increase of the viscoelasticity to compensate the decrease of the feedback postural control gain. It suggests that the functional contribution ratio between the viscoelasticity and the postural control system could be controlled.

CONCLUSIONS

The intrinsic viscoelasticity during standing was successfully measured with the developed system. The role of the intrinsic viscoelasticity in postural stability was estimated as about 32%. The exsitense of a higher postural control system was suggested which modulates the intrinsic viscoelasticity with the environment. The estimation of the stretch reflex gain from the measured response is required to reveal the detailed functional role of the viscoelasticity, stretch reflex and feedback postural control system.

REFERENCES

[1] P.L.Weiss, I.W.Hunter and R.E.Kearney: Human Ankle Joint Stiffness over the Full Range of Muscle Activation lebels, Journal of Biomechanics, 21, 539-544(1988)

[2] M.M.Mirbagheri, R.E.kearney and H.Barbeau:Modulation of intrinsic and reflex contributions to dynamic ankle stiffness with the level of voluntary contraction, Proc. IEEE EMBS-18th, (1996)

[3] T.Sinkjaer, E.Toft, S.Andreassen and B. C.Hornemanin: Muscle Stiffness in Human Ankle Dorsiflexors:Intrinsic and Components, Journal of Neurophysiology, 60(3), 1110-1121(1988)

[4] A.Ishida, J.Hozumi, S.Imai, S.Ryumae and M. Shimizu: Measurement of visco-elastic properties of muscles around the ankle during standing, Frontiers in Medical and.Biological Engineering, 7(1), 35-43(1995)

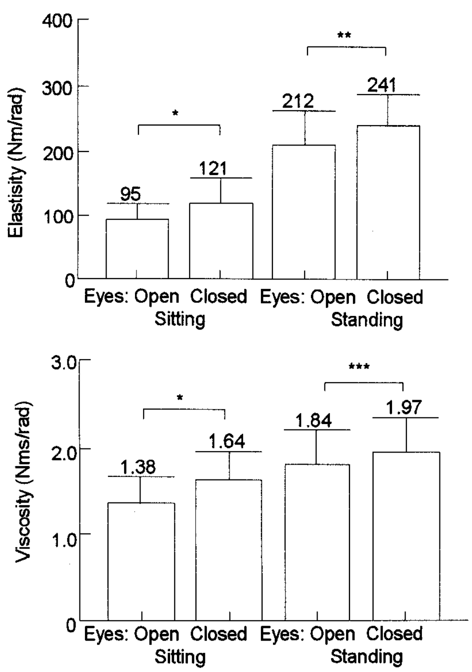

Figure 4. Viscoelasticity during eyes-open or eyes-closed standing. (*: p<0.005, **:p<0.01, ***:p<0.1).