INTRODUCTION
One of the limitations for use of plantar pressure distribution measurement devices is the inability to measure shear force. It seems to keep such devices at a distance from kinetic analysis despite of its portability and convenience in real-time measurement. The purpose of this study was to clarify the effect of ground reaction force components on ankle joint torque during walking. Further, the possibility of estimating ankle joint torque from calculations without the horizontal ground reaction force was examined.

METHODS
Twelve Japanese young male adults (24.5 ± 1.8 yr.) were instructed to walk as usual (Normal Walk: NW) and at three other self-selected speeds (Slow Walk: SW, Fast Walk: FW, and Maximum-speed Walk: MW). Their locomotion was videotaped with a high speed VTR camera, and ground reaction forces on the right foot were measured with a force platform. Joint torques at the ankle, knee and hip were calculated with a link-segment model based on the sagittal plane 2D inverse dynamics method. Followed by the usual inverse dynamics analysis, simulated joint torques were calculated with the horizontal ground reaction force set as zero. In general inverse dynamics, the equations of motion for the foot necessary to derive the ankle joint torque are as follows.

\[
F_{ax} + F_x = m \cdot a_x
\]

\[
F_{ay} + F_y = m \cdot a_y
\]

\[
M_{az} = (r_{px} \cdot F_y - r_{py} \cdot F_x) + r_{pz} \cdot (m \cdot a_y + r_{pz} \cdot a_x - m \cdot g) + r_{py} \cdot (m \cdot a_x - F_y - m \cdot g) + I_z \cdot \alpha_z
\]

(1)

(2)

(3)

where \(F_{ax}\) and \(F_{ay}\) are forces acted by shank (ankle joint force), \(F_x\) and \(F_y\) are horizontal and vertical ground reaction forces (GRF), \(m\) is the mass of foot, \(a_x\) and \(a_y\) are linear accelerations of center of mass (CM) of foot, \(g\) is the acceleration of gravity (-9.8 m/s\(^2\)), \(M_{az}\) is torque acted by shank (ankle joint torque), \(I_z\) is principal moment of inertia of foot about CM, \(\alpha_z\) is angular acceleration of foot, \(r_{px}\) and \(r_{py}\) are position vector components of center of GRF action from foot CM, \(r_{pz}\) and \(r_{py}\) are position vector components of ankle joint center from foot CM. Substituting (1) and (2) into (3),

\[
M_{az} = - r_{dx} \cdot F_y + r_{dy} \cdot F_x + r_{px} \cdot (m \cdot a_y + r_{pz} \cdot a_x - m \cdot g) + r_{py} \cdot (m \cdot a_x - F_y - m \cdot g) + I_z \cdot \alpha_z
\]

\[
= r_{dx} \cdot F_x + r_{dy} \cdot F_y - r_{px} \cdot m \cdot a_y + r_{px} \cdot r_{py} \cdot F_y + r_{px} \cdot m \cdot g + r_{py} \cdot m \cdot a_x - r_{py} \cdot F_x + I_z \cdot \alpha_z
\]

\[
= (r_{dx} - r_{py}) \cdot F_x + (r_{dy} - r_{px}) \cdot F_y + r_{px} \cdot m \cdot a_y + r_{py} \cdot m \cdot g - r_{py} \cdot m \cdot (g-a_y) + I_z \cdot \alpha_z
\]

Each underlined term in the right side of equation (3)’ means contribution of \(F_{ax}\), \(F_{ay}\), \(a_x\), \(a_y\) to the ankle joint torque in order. These terms and their effects on ankle joint torque were discussed.

RESULTS AND DISCUSSION
Figure 1 shows comparison of lower limb joint torques by traditional calculation and by simulated calculation in which horizontal ground reaction force was set as zero. Regardless of walking velocity, the ankle joint torques by two calculations were similar in both the time series pattern and the peak values. On the other hand, knee and hip joint torques were largely different between calculation methods.

The results of each term in equation (3)’ showed that horizontal ground reaction force acted as producing dorsiflexion torque during the first half of the stance phase and as producing plantar flexion torque during the second half. Therefore, the ankle joint torque from the simulated calculation underestimated the dorsiflexion torque just after heel contact and the plantar flexion torque at push-off.

CONCLUSIONS
This study demonstrated the possibility of estimating ankle joint torque without horizontal ground reaction force. However, we should mind underestimations of dorsiflexion torque immediately after heel contact and plantar flexion torque at push-off.

REFERENCES