The Vertical Component of Feet Pressure against Floor at the Initiation of Walking in Hemiparesis

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Summary

The characteristics of the vertical component of the pressure of feet against floor during the initiation of walking known as 'reverseresponse' were compared for the swinging leg of 24 hemiparetic and 4 normal subjects. The patients were classified into 2 groups according to functional grade, a group with a high functional grade (11) subjects and with low functional grade (13) subjects. The 'reverse response' was recorded by a forceplate and estimated on the response amplitude, reaction time and peak time.

The main finding of this study was a reduction of the amplitude on the normal side in the patients with low grade function. The mechanism of this result was analyzed by means of a simple model and the mathematical equation introduced by Onishi. It is suggested that this reduction is indirectly due to the dysfunction of the hip abductor of the paretic limb and compensated for by other mechanisms.

Introduction

During the transition from a symmetrical standing position to walking, the first acting muscles which can be perceived are the muscles of the swinging leg. However, the muscles supporting the trunk, for example, m. sacrospinalis or m. gluteus medius start to contract before the swinging leg is pushed off the floor[1)-3)]. Carlsoo, S. (1966) showed that these muscle actions resulted in the initial change of the vertical force component measured by the force-plate[1)]. This change was the transient increase of the body weight on the swinging leg before releasing from the force-plate, and is therefore called the 'reverse response' by N. Onishi, *et al.* (1980)[2)]. They clasified clear the mechanism of the reverse response by the simple model of the human body. In the mathematical equation and the parameters introduced by them, the amplitude of the reverse response is defined by both acceleration ($\ddot{\theta}$) and tilt angle (θ) of the femur axis to the perpendicular when the body center of the gravity shifts to the supporting leg before the swinging leg pushs off the floor. The $\ddot{\theta}$ is mainly provided by the muscle power of the hip abductor of the swinging leg. The hip adductor of supporting leg also assists but weakly. The θ is a minus factor which reduces the amplitude of the reverse response. (See Fig. 1 and

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the explanation).

So far, these analyses of the reverse response were studied in normal humans. Little data was obtained on patients with upper motor neuron disease. The purpose of this study is to investigate the reverse response of hemiplegic patients who have central nervous system damage and to determine whether or not the reverse response is abnormal and how these parameters are concerned.

Methods

Subjects. The hemiparetic subject group consisted of 10 males and 14 females with an avarage age of 64.1 ±9.8 years. The hemiparesis was right sided in fourteen and left sided in ten subjects. The severity of paresis was different but all of the patients were classified into 2 groups, low grade group 5～9 (11 subjects), high grade group 10～12 (13 subjects) in accordance with the functional grade proposed by Ueda. S.[4] (In this category, the higher the grade, the better the ability). All of them retained the ability to walk with or without the assistance of a cane, but on testing, none of them used a cane. Four normal subjects, with an avanage age of ranging in age 33.5±12.5 years, were also tested for the control.

Procedure. Each subject stood with one leg on a force-plate (KYOWA, ECG-1010BS) and another leg on a wooden plate equal in same height to the force-plate. As soon as a ramp signal was given, the subject stepped off the force-plate and then the amplitude of the foot pressure was recorded on the swinging side. Five trials were tested on each leg. Most of the hemiparetic subjects took asymmetrical standing posture and step with limited speed, specific to the subject. The relations of the amplitude of the reverse response to the step speed and the angle (θs) before stepping were not yet known. These relations were first tested in the normal subjects. As θs is also in proportion to the weight load (L) on one side in this static position, L was shown in figures in stead of θs. The speed of the first step was set, *i. e.,* the slowest possible, ordinary walking and the fastest as possible. Both T and L were normalized by the body weight (W).

Recording. The signal from the force-plate was stored in a data recorder (SONY, A−614) and later was recorded an by X−Y recorder (SAN−EI, 8U16) under displaying on memory scope (NIHONKOHDEN, VC−10).

Results

In the normal group, the relations of the magnitude of the reverse response to both the different weight load on the swinging leg and to the step speed were similar in all subjects. A typical relation is shown in Fig. 2. When the weight load was 50～60% of the body weight, the subject stood symmetrically or with a little weight load on the swinging leg, and the largest amplitude was obtained. Out of this range, the amplitude reduced when the weight load

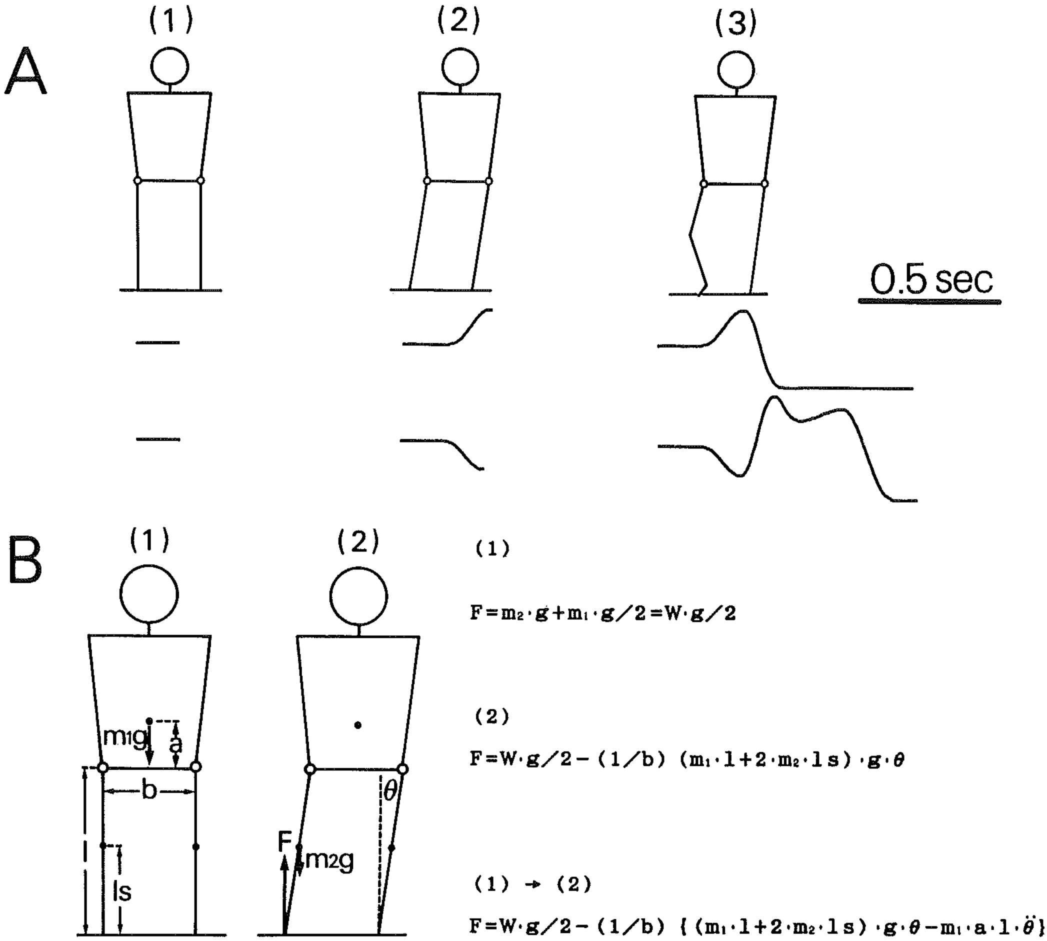

Fig. 1 The pattern of the force change at the initiation of walking recorded by a power-plate (A) and the motor equation introduced by N. Onishi (B).
A : (1) Symmetrical standing position before the initiation of walking. (2) Period of the weight shift to the supporting leg in order to release the weight load on the swinging leg. The force is transiently increased on the swinging side and equally decreased on the supporting side before the weight shifting. (3) Period in which the swinging leg starts to lift and swing. Dotted lines showed no load on the power-plate. Sw is the swinging side and St is the supporting side. B ; In the symmetrical standing posture (1), the force on each side is equal to half the body weight. At the termination of the weight shift (2), the force on the swinging side F is reduced by θ. At the weight shifting from (1) to (2),F is increased by θ and thereafter reduced, because the power is desired for the generation of θ, *i. e.*, 'reverse response' appears. F=vertical force component on the power-plate. $m_1 \cdot g$=the gravity of trunk. $m_2 \cdot g$=the gravity of one leg. I=the length of one leg. Is=the length from the center of the gravity in one leg to the foot. a=the length from the center of the gravity in the trunk to the pelvic joint. b=the length between the pelvic joints. θ ; the tilt angle of the leg at the weight shifting.

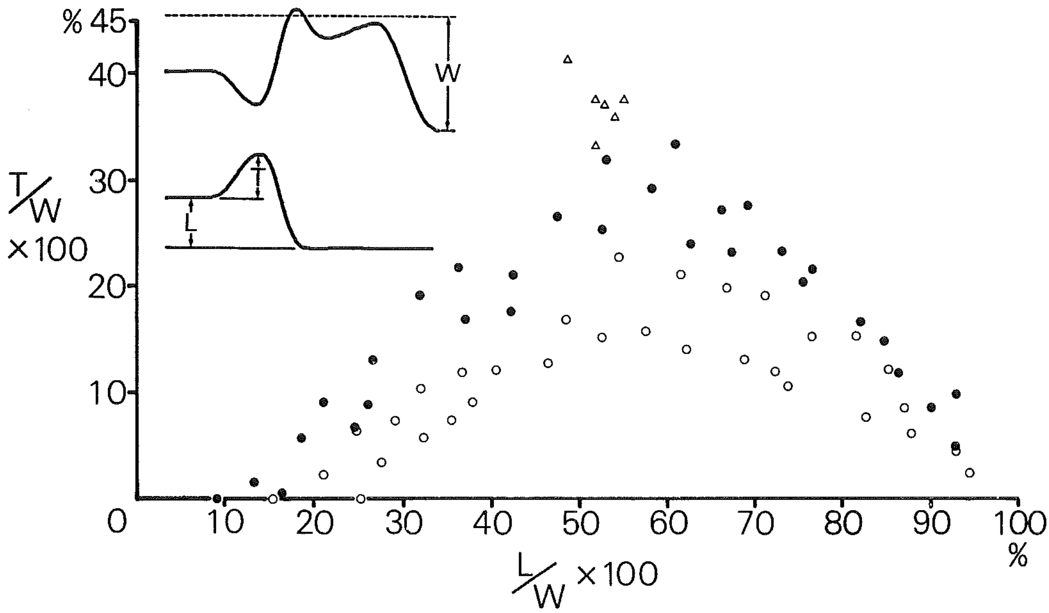

Fig. 2 A typical example of the reverse responses of the swinging leg in normal subjects. The ordinate is a percent ratio of the response amplitude to the body weight. The abscissa is a percent ratio of the weight load on the swinging leg to the body weight. The filled symbols are at ordinary step speed and open symbols at the slowest step speed as possible. Cross symbols are at the fastest step speed possible in equal weight load on both legs (symmetrical standing posture).

Table 1. Average characteristics of the reverse response of swinging or supporting leg in all subjects.
The normal group was tested in symmetrical standing position and paretic group in the position they use in ordinary standing. 1-Rt, r-Rt : Latency (in seconds) from the onset of the signal to the start of the reverse response in left side and right side. 1-Pt, r-Pt : Time (in seconds) from the start of the reverse response to the peak in left side and in right side. Both 1-L/W, r-L/W and 1-T/W, r-T/W (in percentages) : same as Fig. 2. Student's t-test was used to determine a significant difference.
* indicates a difference from the normal ($P<0.01$) and § from another grade group ($P<0.01$).

Subject	r-Rt	1-Rt	r-Pt	1-Pt	r-L/W	1-L/W	r-T/W	1-T/W
Normal	0.234 0.018	0.231 0.026	0.205 0.035	0.208 0.024	47.6 5.5	52.4 5.5	23.0 6.7	24.3 8.5
Right hemi Grade 5 ~ 8	0.398 0.227	0.663 0.612	0.180 0.076	0.170 0.053	30.2* 8.0	65.6* 12.5	9.8* 5.7	7.8* 2.8
Grade 9 ~12	0.306 0.094	0.354* 0.072	0.222 0.042	0.217 0.025	47.6§ 6.1	55.4 6.8	18.1§ 4.9	17.7§ 6.1
Left hemi Grade 5 ~ 8	0.426 0.227	0.407 0.154	0.241 0.065	0.211 0.044	63.5 11.4	34.6 15.3	14.8 11.2	14.3 5.3
Grade 9 ~12	0.925* 0.102	0.456* 0.156	0.202 0.059	0.247 0.116	60.6* 6.6	42.8* 5.8	16.9 6.7	13.6 7.0

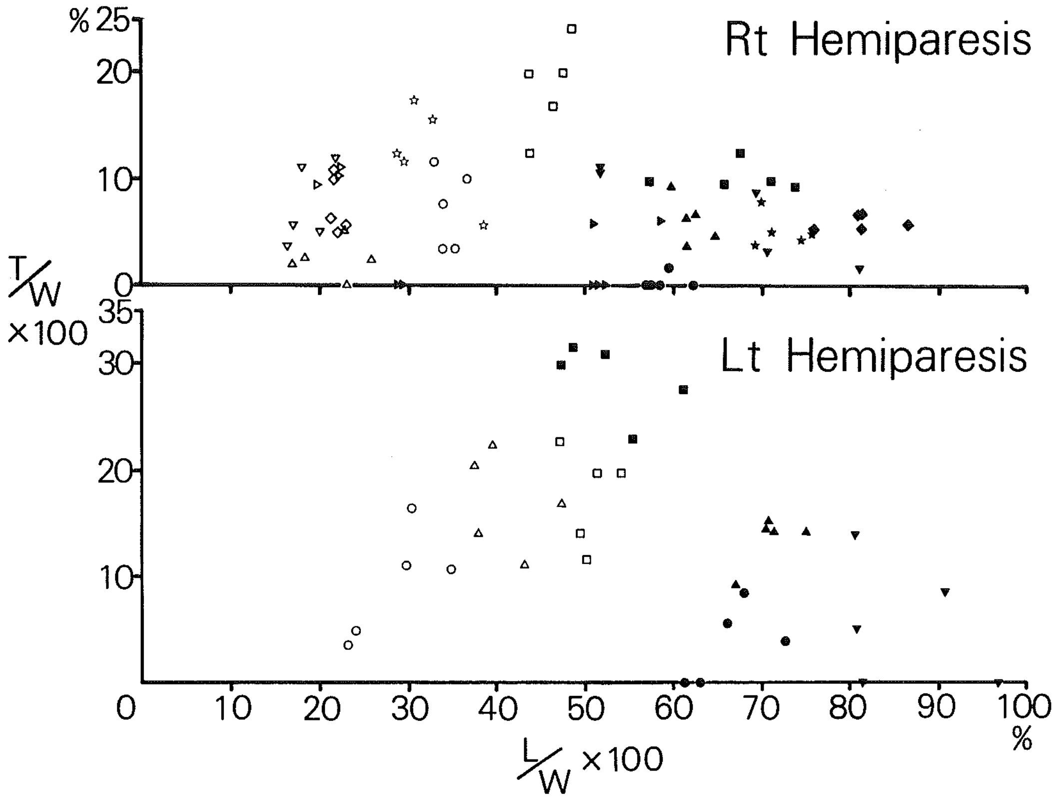

Fig. 3 The reverse responses of swinging leg in patients with right (upper graph) and left (lower graph) hemiparesis.
Ordinate and abscissa are the same as in Fig. 2. The filled symbols are for the normal side, and the open symbols are for the paretic side.

increased or decreased. The response pattern, without the difference of amplitude, was the same as at both the ordinary and the slowest step speed. When the step speed became larger, the amplitude increased.

In all of the hemiparetic patients except the right hemiparetic group with high functional grade, the weight load on the paretic side was smaller than on nonparetic side, *i. e.*, they stood asymmetrically (Table 1).

In the right hemiparetic patients with low functional grade, the amplitude of the reverse response on the nonparetic side were smaller than normal size on the slowest step speed, but on the paretic side was approximately to the normal on the slowest or the ordinary step speed (Fig, 3). In the left hemiparetic patients with low functional grade, the amplitudes in both the paretic and nonparetic sides were within the normal range for ordinary step speed. The amplitude of the left hemiparesis on the nonparetic side, as compared with the right hemiparesis, were close to the normal range. Because the weight load on each leg was differed between patients, the statistical differnce on the amplitude could not be tested. A significant difference was clear in the nonparetic side of all the right hemiparetic subjects and one of left hemiparetic subject because none of the data on these subjects plotted within the range of all the normal data.

The latency from the onset of the signal to the start of the reverse response (Rt) and the time from the start to peak (Pt) were summarized in Table 1. Rt in the group with a high functional grade were longer than that of the normal group ($P<0.01$). In the low grade patients, a significant difference was not seen because there was a lot of dispersion between the subjects.

Conclusion and Discussion

The standing posture before the initiation of the walking was asymmetrical in the hemiparetic patients. he body weight was unequally loaded on the legs with the greater weigbt loaded on the normal leg by a tilting of the body (Actually, as the tilting arose at the pelvic joints, the angle of the longitudinal axis of upper trunk to the perpendicular was zero). This asymmetrical posture which was caused by the weakness in the affected leg was specific to the patients.

At the initiation of walking, in all of the right hemiparetic patients with low functional grade, the amplitude of the reverse response on the normal side was smaller than on the paretic side and also smaller than that of the normal group with the same weight load condition. The amplitude on the nonparetic side was within the normal range.

The results of this study indicated that a mechanical change bad occurred in the hemiparetic patient. By Onishi's model and mathematical equation, the response amplitude was defined both accelaration ($\ddot{\theta}$) and tilt angle (θ) of the femur axis to the perpendicular during the body's shifting to the supporting leg. At first, it was assumed that the $\ddot{\theta}$ at swinging the paretic leg of the patients with low grade function would be reduced. The reason was that the $\ddot{\theta}$ was mainly produced by the power of the hip abductor of the swinging leg[2], therefore the reduction of the $\ddot{\theta}$ might be due to the weakness of these muscles. However, it was not true because the amplitude on the normal side having enough muscle power was decreased. There are possible reasons why $\ddot{\theta}$ was decreased at the swinging of the normal leg. One of reasons is that the reduction of $\ddot{\theta}$ was indirectly caused by the weakness of the paretic muscle. As the paretic leg muscles have not the enough power to support the body weight during the weight shifting to the supporting leg, the motor pattern which make the $\ddot{\theta}$ decrease was programmed. However, as some patients were able to initiate the step even at the condition of the $\ddot{\theta}=0$, the weight shifting was made up by the other factors, for example, a velocity ($\dot{\theta}$) instead of the $\ddot{\theta}$ might be used for weight shifting.

For a long time, the patients often have a specific posture, for example, hip flexion, abduction and external rotation, from which the contractures were resulted[5]. The hypertonus of the hip abductor also restricted the mobility of the hip joint on the paretic side[6]. Most of the patients in this study suffered spasticity of the hypertonus, which elicits the stretch reflex to the hip abductor of the supporting leg and prevents the muscle from elongating during weight shifting. To compensate for the reduction of the θ, it is theorized that the body weight is shifted not by increasing the θ at the hip joint but by tilting the upper trunk toward the supporting side.

To obtain the normal amplitude of the reverse response, the physical therapy to improve these mechanical deficits must be applied. For example, slow stretching of the hip joint toward the adduction is effective for the hip joint contracture and for the hypertonus of the hip abductor. At the same time, the muscle power of the m. gluteus medius on the paretic side must be strengthen and the weight loading on the paretic leg must be trained. If the abductor on the paretic side is only strengthened a little the assistive adductor on the normal side must be trained to substitute. In the final stage of the training, the therapist must instruct the patient on the proper mechanical process at the initiation of a step and make them continue the pattern.

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