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QUANTITATIVE ANALYSIS OF RISING FROM A CHAIR IN HEALTHY AND HEMIPARETIC SUBJECTS

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ABSTRACT. In 15 healthy and 20 hemiparetic persons we studied standing-up by two force-plates. Phases before and after the seat-off, force distribution and centre of gravity displacement were assessed. The patients rose significantly slower. The force ratios after seat-off differed significantly between the groups (0.88 vs 0.68). Left/right hemiparetic patients put more weight on the affected limb in 18%/11% of the trials before seat-off, with its insufficient use after it mainly in the left patients. At seat-off, projection of the centre of gravity fell within the support area in hemiparetic patients, and 3 cm behind it in healthy subjects. With larger lateral displacement of the centre of gravity in the hemiparetic group, left hemiparetic patients mostly shifted their weight to the non-affected side and right hemiparetic patients to both sides. Weight distribution and mediolateral displacement of the centre of gravity in the left and right hemiparetic patients were considered.

Key words: standing-up, posture, hemiparesis, weight distribution, centre of gravity.

Re-establishment of sit-to-stand transfer is a primary concern of physiotherapy in the neurological rehabilitation of hemiparetic patients.

Hemiparetic patients rise slowly, insecure, and tend to put more weight on the non-affected limb. In two reports on sit-to-stand transfer of hemiparetic and healthy subjects, the patients rose slower with a time factor of 1.7 (5) and 1.5 (14) when compared with healthy persons. Average ratios of the vertical forces on affected vs. non-affected limb were 0.6 when the patients were requested to rise as usual, and 0.8 when asked to stand up as symmetrically as possible (5). In the same report these ratios were close to 1 for the control subjects.

During standing-up patients are normally encouraged by physiotherapists to put weight on both lower limbs, to incline forward, and to avoid mediolateral displacements of the head-arm-trunk segment (3, 4).

In order to validate clinically observed differences and to introduce parameters capable of describing therapeutic effects, characteristic phases of the standing-up (7) as well as weight-distribution between both limbs (5) before and after seat-off event were assessed in healthy and hemiparetic subjects. Furthermore relative displacements also in the medio-lateral direction of the centre of gravity and its projection to the area of support were estimated by a two-fold integration of the ground reaction forces (2, 6). Differences between the right and left hemiparetic patients were assessed. Recording of ground reaction forces by two force plates provided a clinical applicability of the measurements.

SUBJECTS AND METHODS

Subjects

Experimental group (9 female and 11 male patients) and control group (9 females and 6 males) were matched for age, weight and height. The healthy subjects with a mean age of 41 years (range: 37–56) had in average 68.4 kg (range: 41–97) and 172 cm (range: 156–184). The hemiparetic patients with a mean age of 43 years (range 22–60) weighted in average 81 kg (range 57–105) and were 173 cm high (range 153–186). Twelve patients suffered from right and 8 from left hemiparesis. The etiology was in all cases an ischemia in the *a. cerebri media* or *a. cerebri anterior* region. Mean stroke interval was 18 weeks with a range of 12–26 weeks.

All hemiparetic patients could stand up independently and were able to understand and follow instructions. A neglect syndrome, resulting in non-perception and non-use of the affected lower limb (1), was found in 3 of the left hemiparetic patients. It was assessed by the behavioural inattention test (13). Additional orthopedic or neurological impairments concerning mobility were excluded.

Data acquisition

Two embedded 50 × 50 cm triaxial 8294 Kistler force platforms with 9865A charge amplifiers were used for the measurement of ground reaction forces with 125 Hz per channel and converted into ASCII-files with processing of selected parameters (12).

The seat was placed on one of the force plates and the subject's feet on the other one. The seat without armrests was adjusted in height with the femoral condyles of the patients. The subjects were sitting upright with thighs supported half-length by the seat and the shanks approximately 10° flexed over the vertical. Position of the feet at 20°, toes 30 cm apart, was marked and kept constant during all consecutive trials.

According to the investigation plan, subjects had to stand up at self-adopted speed five times as evenly as possible. The arms were outstretched and the fingers folded. Mean parameters of 5 consecutive trials were calculated for each subject. A two-folded *t*-test for independent samples (alpha = 0.01) was applied by SYSTAT statistic software package to compare the group mean values.

Selected parameters

During standing-up two phases, one before and another after seat-off event, were distinguished by diagrams of the vertical (Fz, Fs) and horizontal forces (Fx) (7). Typical force plots of a right hemiparetic patient during standing-up are given in Fig. 1.

Fz denoted the vertical force component of both plates and Fs was the vertical sit-force. The beginning of rising (Tbegin) was assumed when the horizontal force component Fx differed from zero by more than 20% of the peak value for at least 50 ms. At seat-off event (Tseat-off) the seat was completely unloaded, i.e. the vertical sit-force, Fs, was less than 3% of the initial value for at least 50 ms. This event, where the stable three point support changed to a temporary unstable two point support, was chosen to separate the phases of standing-up. Tquit denoted the end of rising, when the vertical force component of both plates, Fz, was in an interval of 5% within the entire body weight for at least 100 ms.

Total rise time (TRT, interval between Tbegin and Tquit) and relative temporal occurrence of seat-off event were calculated.

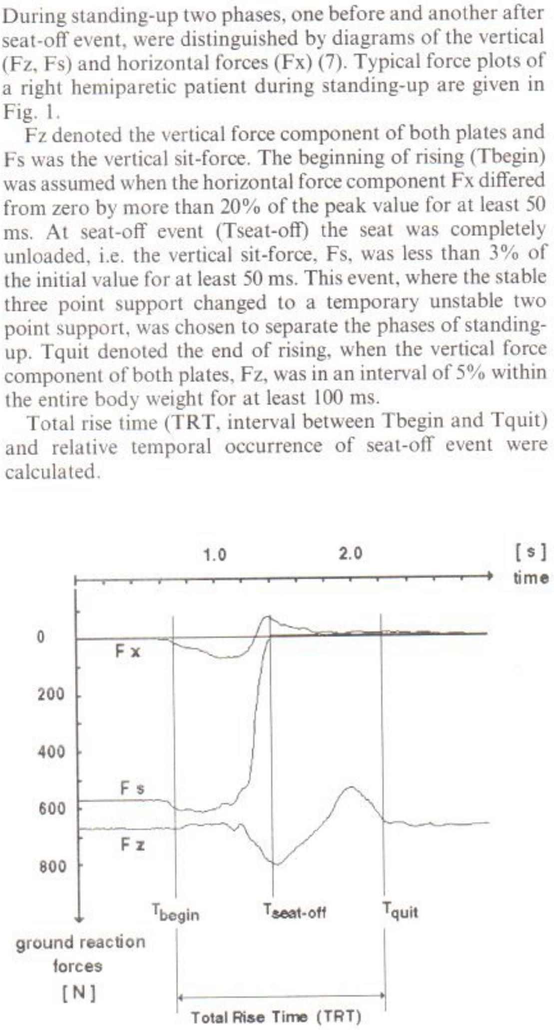

Fig. 1. Force diagrams of a right hemiparetic patient during standing-up: *Fs* is the sit-force, *Fx* and *Fz* are the entire arterio-posterior and vertical components of the ground reaction forces.

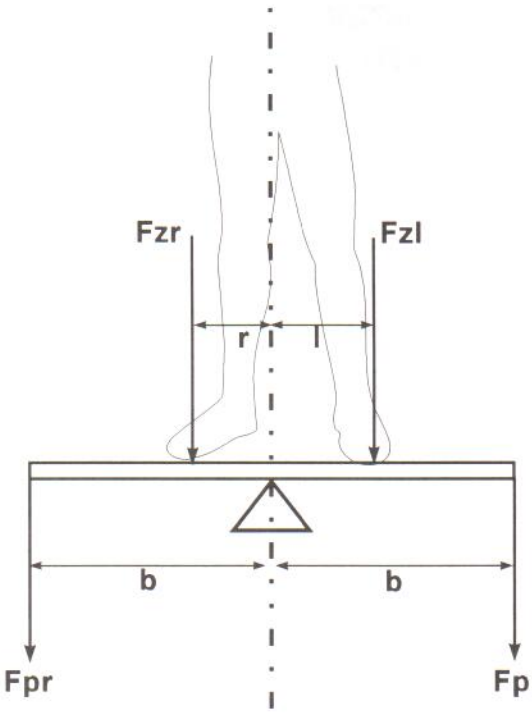

Fig. 2. Vertical forces under right and left foot: *Fzr* and *Fzl*, right and left forces measured by the force-plate: *Fpr* and *Fpl* and their distances from the anterior-posterior axis of the force-plate.

Distribution of the vertical forces between both limbs: Fzr, Fzl (Fig. 2) was assessed before and after seat-off and normalized by the body weight. Fzr and Fzl were computed from torques acting about the anterior-posterior axis. Fpr and Fpl in Fig. 2 are the right and left forces measured by the force-plate, 2b is distance between the right and left force transducers, r and l are distances of the centre of right and left foot from the center of the force-plate. Right and left vertical forces were calculated from the equations:

$$\mathrm{Fpr} + \mathrm{Fpl} = \mathrm{Fzr} + \mathrm{Fzl}$$

$$\mathrm{Fpr} \times \mathrm{b} - \mathrm{Fpl} \times \mathrm{b} = \mathrm{Fzr} \times \mathrm{r} - \mathrm{Fzl} \times \mathrm{lFzr}$$

Calculation of this phase-dependent force distribution was based on the assumption that the center of pressure of each foot was not moving markedly. It remained close to the center of outline area of the foot or was displaced in anterior-posterior direction. Additionally, average force ratios (right/left for healthy, affected/non-affected for hemiparetic subjects) were computed for the time intervals before and after seat-off event.

Displacement of the centre of gravity (COG) was calculated by a two-fold integration of the total ground reaction forces (2, 6). Absolute COG displacements in the vertical (Dz), anterior-posterior (Dx) and medio-lateral (Dy) directions were computed before and after seat-off. A typical anterior and vertical displacement of the COG is given in Fig. 3 for a healthy person and a left hemiparetic patient. Vertical projection of COG at seat-off event and its anterior-posterior distance from the heel edges were assessed. The

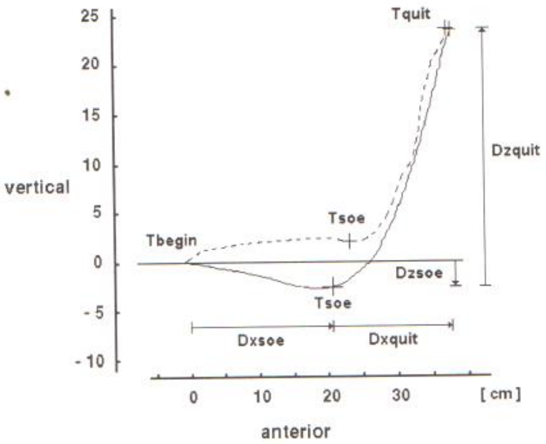

Fig. 3. Anterior and vertical displacement of the centre of gravity of a healthy subject (*solid line*) and a left hemiparetic patient (*dotted line*): *Tsoe* = seat-off event, *Dxsoe/Dzsoe* = anterior/vertical displacement before seat-off event, *Dxquit/Dzquit* = anterior/vertical displacement after Tsoe.

displacements of COG in all directions were related to body height.

RESULTS

Time-course analysis

As shown in Table I, the hemiparetic subjects had a 25% longer total rise time (TRT) than the control persons ($p < 0.001$). Relative occurrence of seat-off event (Tsoe%) did not differ significantly between the two groups.

Body weight distribution

Absolute mean force difference between the right and left (affected and non-affected) lower limb, normalized by the body weight, is presented in Table II. It was significantly different between both groups before seat-off ($p < 0.001$) and afterwards ($p < 0.001$). It was 136% larger before seat-off and 87% larger after it in the hemiparetic group.

Right/left (in healthy) and affected/non-affected (in hemiparetic subjects) mean force ratios were 0.96/0.94 before seat-off (not significant) and 0.88/0.68 afterwards ($p < 0.001$). Single trials were considered asymmetrical when the ratio was above 1.05 or below 0.95. Thus patients with a left/right hemiparesis put more weight on their affected limb in 18%/11% of the trials before seat-off. Afterwards none of the left hemiparetic patients put more weight on the affected

Table I. *Mean values and standard deviation of total rise time (TRT) and relative occurrence of seat-off event (Tsoe) in % of total rise time*

	Healthy $n = 15$		Hemiparetic $n = 20$		Significant
	Mean	SD	Mean	SD	p
TRT [ms]	1576	153	1975	854	0.000*
Tsoe [%]	45.2	4.1	42.8	7.2	0.013

* Significant

Table II. *Mean values and standard deviations of absolute force differences between both lower limbs and their ratios before and after seat-off event*

Fdsoe, Rsoe: force difference and ratio before seat-off event, Fdquit, Rquit: force difference and ratio after seat-off event.

	Healthy $n = 15$		Hemiparetic $n = 20$		Significant
	Mean	SD	Mean	SD	p
Fdsoe [%]	2.5	1.7	5.9	5.2	0.000*
Rsoe	0.961	0.042	0.935	0.121	0.070
Fdquit [%]	14.0	10.6	26.2	19.1	0.000*
Rquit	0.881	0.268	0.680	0.321	0.000*

* Significant

Table III. *Mean values and standard deviations Dxsoe, Dysoe, Dzsoe: anterior, lateral and vertical displacement of the centre of gravity before seat-off event; Hsoe: anterior-posterior distance of the centre of gravity projection from heel edge at seat-off; Dxquit, Dyquit, Dzquit: anterior, lateral and vertical displacement of the centre of gravity after seat-off event; [%H]: related to body height; MVX, MVZ: maximum anterior and vertical velocity of centre of gravity*

	Healthy $n = 15$		Hemiparetic $n = 20$		Significant
	Mean	SD	Mean	SD	p
Dxsoe [%H]	8.5	1.3	8.8	3.5	0.517
Dysoe [%H]	0.9	0.6	1.6	1.4	0.000*
Dzsoe [%H]	−0.1	1.0	0.2	2.4	0.177
Hsoe [cm]	−3.0	3.5	0.2	6.2	0.000*
Dxquit [%H]	6.4	1.9	4.8	2.2	0.000*
Dyquit [%H]	1.2	0.9	1.8	1.5	0.002*
Dzquit [%H]	15.1	1.4	14.0	2.8	0.20
MVX [m/s]	0.43	0.05	0.38	0.08	0.000*
MVZ [m/s]	0.52	0.09	0.45	0.14	0.002*

* Significant

limb, while this could be shown in 16% of the trials of the right hemiparetic patients.

COG-displacement

Relative displacement of COG is presented in Table III. Before seat-off the displacement in the anterior and vertical direction did not differ between the two groups. The patients and healthy subjects evenly shifted their COG upwards and downwards before leaving the seat.

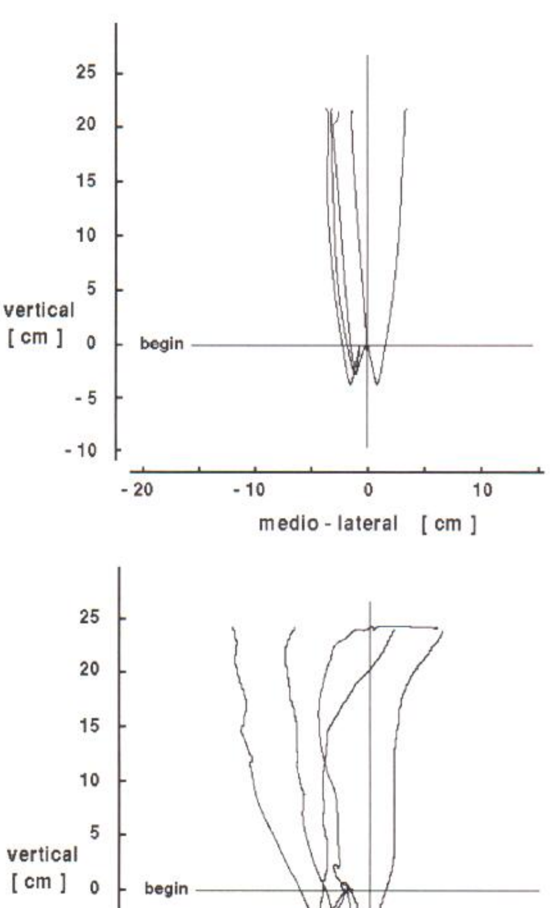

Fig. 4. Medio-lateral and vertical displacement of the centre of gravity during five consecutive trials of a healthy subject and right hemiparetic patient.

At seat-off event, projection of COG of hemiparetics fell into the feet area of support. It was 0.2 cm in front of the heels, whereas COG projection of the control subjects was 3.0 cm behind the rear heel edge ($p < 0.001$).

Within the time interval from Tsoe to Tquit the hemiparetic patients shifted their COG 33% less in the anterior direction ($p < 0.001$), while the vertica displacement related to body height was not significantly different. Maximum velocity of the displacement of COG in the anterior/vertical direction was 13%/14% faster in the control subjects ($p < 0.001$ $p = 0.002$).

In the medio-lateral direction, absolute COG displacement was significantly different between the groups. In the hemiparetic patients COG was shifted laterally for 78% more before ($p < 0.001$) and 50% after seat-off event ($p < 0.002$) than in the healthy subjects. Medio-lateral and vertical displacement of COG during five consecutive trials is given in Fig. 4 for a healthy person and a right hemiparetic patient. From the initial left position the COG of the patient in the lower part of Fig. 4 was shifted 4 times to the left (non-affected) and once to the right (affected) side before seat-off event. It normally occurred when the COG reached the lowest point. After the seat-off event the COG remained on the left side most of the time in the four trials, then shortly before the end shifted to the right in two of them, finishing so on the right (affected) side in three of the five trials.

In single trials a shift was assumed when COG displacement exceeded 1 cm. In general, left hemiparetic patients shifted their COG to the non-affected side before and after SOE except in one trial. Right hemiparetic patients shifted their COG equally to both sides before and after seat-off.

DISCUSSION

Time-course analysis

In this study, the time needed to rise was 1.25 time longer in the hemiparetic patients when compared to the healthy controls. In two previous reports comparing sit-to-stand transfer of healthy and hemiparetic subjects, factors of 1.5 (14) and 1.7 (5) were recorded.

The smaller factor for comparably affected subject in this study might be explained by different definitions of begin and end of standing-up. The criteria in this study: Fx, the horizontal force component exceeding 20% of its peak value to define the begi and Fz, the vertical force component, within a 5% interval at body weight to define the end excluded minor head-arm-trunk oscillations of the hemiparetic patients. They, however, often occur at the beginning and end of standing-up.

In the other two reports the start of rising was defined either by visible deviation of the Fx-trajectory from its baseline (14) or by anterior movement of the head (5) which probably resulted in an earlier identification of the beginning of movement in both studies.

To define the end of standing-up a comparable criterion was selected in the first report, whereas the authors of the second study visually marked the end of forward displacement of the pelvis (5). Correspondingly, the absolute times needed for standing-up were markedly longer (3.7 s vs. 1.98 s) there. Absolute values of the control subjects in this study (1.58 s) agree with a number of reports: 1.88 s (9), 1.55 s (10), and 2.0 s in persons with an age over 65 years (8).

For healthy persons it was reported that relative occurrence of seat-off event within the total rise time was independent of its duration (10). In this study there was no difference concerning that point when comparing healthy and hemiparetic persons. This might imply that both groups used a similar motion control pattern for the standing-up.

Weight distribution

The absolute force differences between both limbs were significantly larger in the hemiparetic patients before and after seat-off supporting the therapeutic significance of an even force distribution between both legs. The corresponding mean right/left or affected/non-affected ratios, however, differed only after seat-off event (0.88 healthy vs. 0.68 hemiparetic subjects). This divergent result was explained by the fact that in 18%/11% of the trials the left/right hemiparetic patient put more weight on the affected leg before leaving the seat. Afterwards, when the body weight was only supported by two bases, as expected, poor use of the paretic leg could be demonstrated. The ratio of 0.68 in the hemiparetic group after seat-off corresponded with previously reported values of 0.60 when rising as usual and 0.80 when instructed to stand-up as evenly as possible (5). The authors, however, did not distinguish different phases of the standing-up.

Poor use of the affected leg after seat-off was more pronounced in the left hemiparetic patients, who put more weight on the non-affected leg in all but one of the trials, while this was not the case in 16% of the trials of the right hemiparetic patients. This finding might be explained by dominance of the right parietal lobe for spatial orientation and body alignment (1), which was presumably damaged in the left hemiparetic patients in this study. An overt neglect syndrome could be demonstrated in 3 of them.

COG-displacement

The vertical and anterior COG-displacement prior to seat-off did not differ between both groups. COG projection of the hemiparetic patients was within the feet area while it was still behind it in the normal subjects at seat-off event. This reflected the strategy of the patients to move their COG to a more favourable position at and just after seat-off (11). Higher dynamics in the healthy subjects allowed them to leave their COG behind the area of support at the beginning of two-base support. Correspondingly, the maximum velocities of COG in the vertical and anterior direction were slower in the hemiparetic group. Assuming a stable posture, the COG had to be in front of the ankles in both groups at the end of standing-up. Therefore the normal subjects shifted their COG 33% more to the anterior direction than the hemiparetic subjects after seat-off. The height-related vertical displacement was not different between both groups.

Clinically observed lateral shifts of the head-arm-trunk segment were displayed in a 78%/50% more lateral shift of COG in the hemiparetic patients before/after seat-off event. Left-hemiparetic patients mostly shifted their COG to the non-affected side whereas the direction was equally distributed in the right hemiparetic patients. This side-dependent pattern corresponded to the force distribution data.

The applied method enabled visualisation of the uneven weight distribution and lateral body shift in the rising hemiparetic patients, particularly during the unstable two-base support after seat-off event. The therapy of sit-to-stand transfer should carefully consider a symmetric force distribution and lateral body alignment, especially in the left hemiparetic patients.

With the lower dynamics of standing-up the patients leaned more forward to bring the projection of COG within the area of two base support at seat-off event. The larger ascending speed in the healthy subjects allowed them to stand up with the COG projection behind the rear heel edge. If the patients were encouraged to rise faster, their energy consumption would be lower with possible improvement of the symmetry. The unchanged relative occurrence of seat-off event suggests a constraint motion control pattern which might at the same time alleviate unwanted synergies.

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