STABILITY DURING STANDING FOR 30 MINUTES IN A HYBRID FRO

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ABSTRACT

A study of the stability of standing in a hybrid floor reaction orthosis was undertaken to find out if the subject's measured stability was consistent throughout the 30 minute trial. The test was done using both hands on the upper limb support and with only the left hand on the support. Results indicated the subject's stability was comparable during the entire 30 minutes and under both hand support conditions.

KEY WORDS: Standing, hybrid orthoses, sway measurement, paraplegia.

INTRODUCTION

Paraplegic standing has attracted a large amount of attention since functional electrical stimulation (FES) was introduced (Bajd et al. 1982). Standing is of interest from both the functional and therapeutic points of view. In order to be truly useful, a method of standing should be functional to allow standing for daily tasks, such as reaching for objects and to aid in social situations where a wheel chair is too low to interact properly with the environment. The method of standing should also be therapeutic, to allow standing for long periods of time, in order for the subject to have the full physiological benefit of standing, including a reduction in incidence of pressure sores (Coghlan et al., 1980).

In the first instance, functional electrical stimulation (FES) can be sufficient. In the second, problems arise when some subjects fatigue too quickly if they stand using only FES to brace their knees. To overcome this difficulty, the idea of a hybrid system was developed, to combine the strengths of both orthotics and FES.

Early results of a study of the stability of stance, using a hybrid system for standing, during 30 minutes are presented.

obtained by averaging by eye the results for his three normal subjects. We can use these diagrams to build a sequence of torques, attempting to use single-joint and double-joint muscles appropriately, and using synergists which have the same root value as much as possible (Table 5). It appears that through the gait-cycle from toe-off to toe-off the sequence of activation of ipsilateral roots is L2-L3-L4-L5-S1-S2-L2- ..(with some overlap), as indicated in the notional pattern of stimulation sketched in the upper part of figure 1.

Movement	Root value
Hip flexion	L2,3
Hip Adduction	L2,3
Hip abduction L(4),5,S1	
Hip extension	L5,S1,(2)
Knee extension	L3,4
Knee flexion	S1
Foot dorsiflexion	L4,5
Plantar flexion	S1,2

Table 4. Likely usual major movements from motor root stimulation (derived from Tables 2 and 3)

PROBLEMS

Questions remaining to be resolved include the following:

1. One obvious exception to this general pattern is the need for weak dorsiflexion (L5) from toe-off until late swing. Just sufficient dorsiflexion to prevent foot-drop is needed during swing, while at heel strike strong dorsiflexion is required, in order to let the foot down to plantargrade in a springy way. However, L5 is otherwise inappropriate during the swing phase, because is causes hip extension and abduction. It becomes appropriate just at heel-strike, when hip abduction is called for as well as strong dorsiflexion. So it may be necessary to arrange for weak toe-raising during swing to be achieved with a spring, calliper or peroneal stimulator.
2. The lower extent of the innervation of iliopsoas. Strong hip flexion from L5 would be a sever embarrassment during the stance phase of gait, but weak hip flexion would not matter much. Only Brain [11] predicts any hip flexion from L5.
3. Will it be necessary to cut obturator nerves? Pedotti's data do not cover coronal forces, but it seems likely that strong adduction during the swing phase would be a problem, leading to scissoring. However, simple self-observation shows that adductors are activated simultaneously with hip flexion at toe-off, so some adductor action in this phase is clearly

knee became unstable, both legs would be stimulated. Figure 2 is a diagram of the output of the knee strap tension transducer and the corresponding stimulation patterns.

The computer program for standing had four states: sit, stand up, stance and

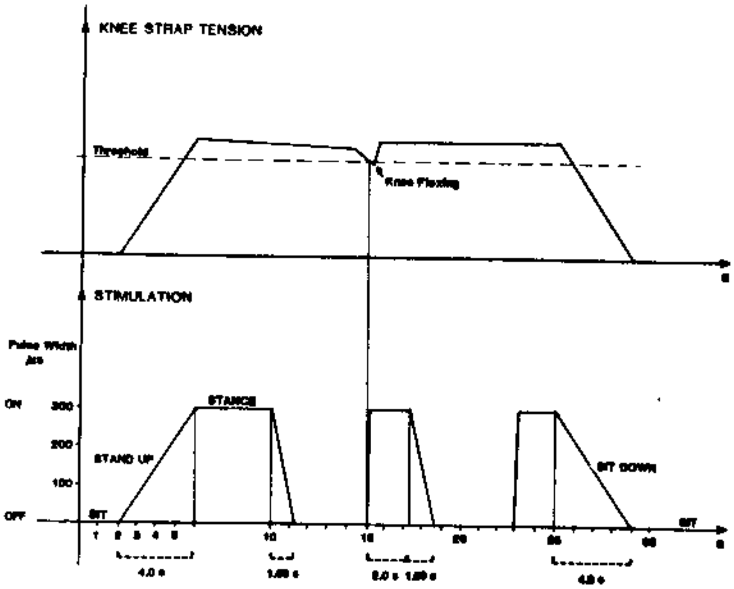


Figure 2. Knee tension controlled standing stimulation sequence. The timing for the stimulation is drawn to scale. The output from the knee tension transducer is simplified for illustrative purposes.

sit down. The state called stance presented the option of using the knee extension controller or using continuous FES to maintain stance.

During the state called sit, all stimulation was turned off as the subject was sitting in his chair, before or after standing. While the subject was sitting, the thresholds for the transducers and the current output of the stimulator could be set. The transducer thresholds could be altered at any stage, as long as no stimulation was being used at the same time.

Stand up was the state that allowed going from sitting to standing. A ramp of stimulation was applied. The pulse width was changed from 0 to 300 microseconds duration over a 4 s period. Sit down was similar, except the ramp decreased from 300 to 0 microseconds pulse width in 4 s.

The state of stance was maintained by delivering pulses of 300 microseconds duration at a repetition rate of 20 Hz. If the knee extension controller option was selected, the tension at the knee straps would be checked constantly and if safe conditions were found, i. e. the tensions found were above the set thresholds, the stimulation would be ramped off taking 1.66 s to do so. This gentle ramping was used to prevent oscillations that had been observed in previous implementations of this system.

If the knee then became unstable, the controller would start stimulation for 2 s and then ramp down taking 1.66 s to do so. When the signal was given to change states to sit down, stimulation was given for 2 s, before the descending ramp was initiated.

It was expected that during standing in the hybrid FRO the stimulator would be used minimally with the FRO staying mostly in its region of conditional stability, thus allowing stable standing for long periods of time by avoiding muscle fatigue.

The stand up stimulation sequence used was an open loop ramp. The subject moved to the edge of the seat with both feet positioned on the floor. After the signal to start the sequence was given, there was a delay to allow the subject to prepare for the manoeuvre by holding the upper limb support to assist with his upper limbs as the quadriceps were activated. Once upright, the subject leaned forward to hyperextend the hip. He remained standing with continuous FES applied until the closed loop knee extension controller was started, when all stimulation was turned off until a destabilizing event at the knee was detected and stimulation came on in the manner described above. To sit down again, the sitting open loop sequence was started. As the stimulus ramped down, the subject again assisted with his upper limb for a gentle descent onto the seat.

METHODS

It was of interest to measure whether or not the subject remained standing with the same degree of stability during 30 minutes, or if tiredness and muscle fatigue affected the stability of stance achieved. This would be important from a safety point of view, were this device to be used for therapeutic standing away from the laboratory environment.

Previous results (Mayagoitia and Andrews, 1989) showed standing in the hybrid FRO was more stable and consistent than standing using FES or a knee ankle foot orthosis under a number of vision and hand support conditions. They also found that the forces exerted by the upper limb during stance were only balancing and not loading forces.

To determine the stability achieved, a number of parameters were calculated from measurements made on a Kistler force plate of the subject's centre of pressure travel.

Subject

One sensory and motor complete T6-7 male paraplegic of 22 years of age, 5 years after his injury, who stands regularly in his knee ankle foot orthosis, and who exercises daily with FES on his quadriceps volunteered for the tests. He was in good health and did not take medication or suffer from illnesses that might impair his balance. He is right handed and has been found to be more stable when he uses only his left hand for support during standing than when he uses only his right hand (Mayagoitia, 1989).

Protocol

The subject was asked to stand quietly using the hybrid system described, on the central area of a Kistler force plate. After he stood up, the knee tension based controller for stance was started and immediately a first measurement of 15 s duration was made. Data were sampled at 50 Hz using an analog to digital converter (Amplicon PC-26) and stored on a portable IBM compatible personal computer (Compaq II). Thereafter, data were collected at 5 minute intervals for 15 s periods, taking the last sample at 30 minutes. The subject then sat down. The test was limited to 30 minutes since the subject sometimes gets pain in his back after standing for long periods of time, and it was sought to prevent this from happening as to avoid discomfort to the subject and as it might have an influence on the measurements.

One set of data were collected with the subject using both hands on a hand support. For two additional sets of data the subject only used his left hand for support. In all cases the hand support used was a rollator.

Analysis

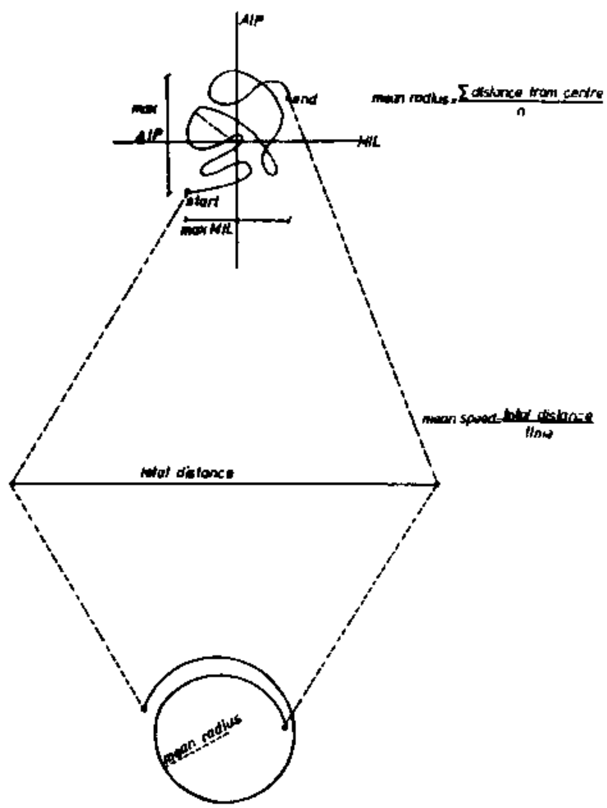


Figure 3. Diagram of a Centre of Pressure Path and the Parameters derived from it (after Cybulski and Jaeger, 1986).

The data obtained were filtered digitally with a low-pass finite impulse response filter at a cut-off frequency of 7.5 Hz, a span of 51 and using a Hamming window. A number of parameters were calculated from the data: the mean speed of the displacement of the centre of pressure, the mean radius of the centre of pressure, and the maximum displacements in the anterior-posterior (A/P) and medio-lateral (M/L) directions.

The mean speed was interpreted after Cybulski and Jaeger (1986) as an indicator of the regulatory activity of the balancing system, the mean radius as a reciprocal measure of the effectiveness of balance, i.e. a measure of stability. The maximum displacements gave an estimation of the size of the base of support used by the subject. Their lengths indicating the relative stability in each of the A/P and M/L planes. Figure 3 has a drawing of a centre of pressure path and the parameter derivation from it.

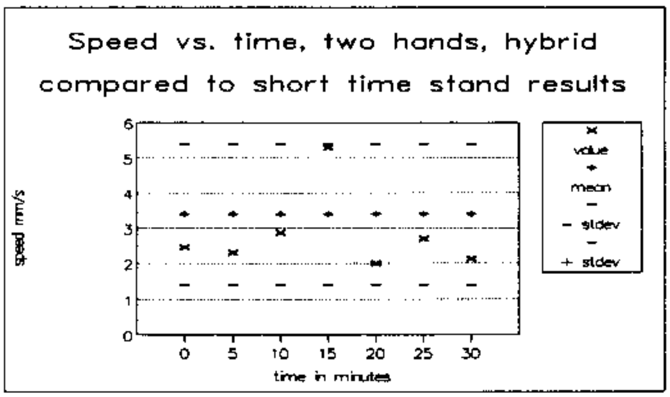
RESULTS

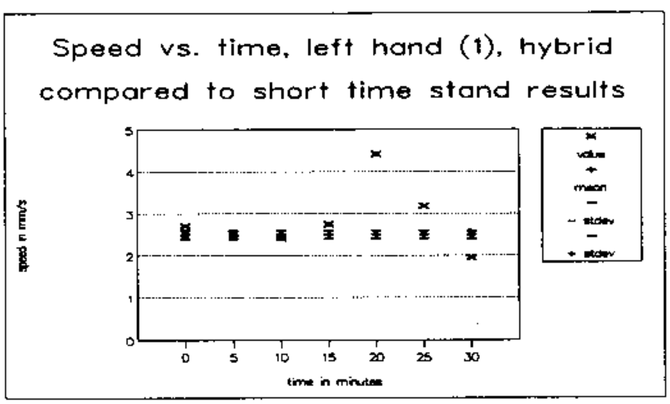
Figures 4 to 7 contain the calculated values for speed, radius, maximum A/P and maximum M/L in each of the three tests. The mean and a one standard deviation interval of the previous results for standing for short periods of time under the same conditions are plotted as well, to serve as a base of comparison. Table 1. Contains the means and standard deviations calculated for each of the parameters for the three tests done. Table 2. Contains the previous results for the same hand support conditions.

	speed mm/s	radius mm	Max A/P mm	Max M/L mm
Two hands				
mean	2.8	1.7	5.7	5.6
st. dev.	1.1	0.6	2.4	1.9
Left hand				
(1) mean	2.9	1.9	4.5	6.9
st. dev.	0.7	0.5	1.2	1.3
(2) mean	3.0	1.7	5.5	6.0
st. dev.	0.6	0.4	1.9	1.3

Table 1. Means and standard deviations of the seven values found for each of the three trials.

The stimulation never came on during data collection. It came on 6 times during the two hands supported test, 8 times during the first left hand test and 5 times during the second left hand test.





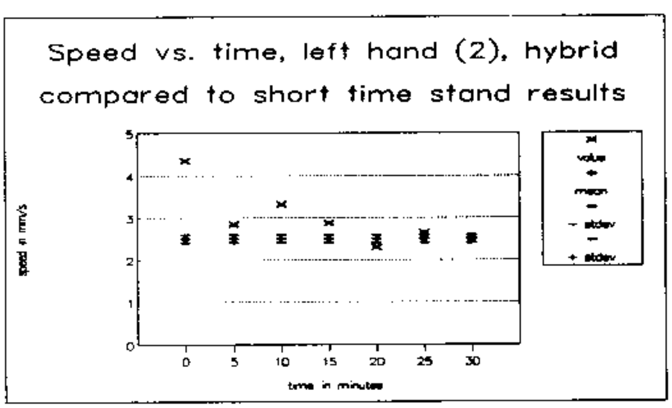
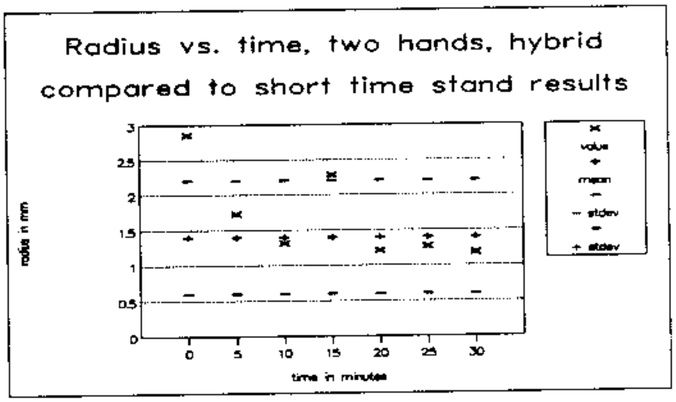
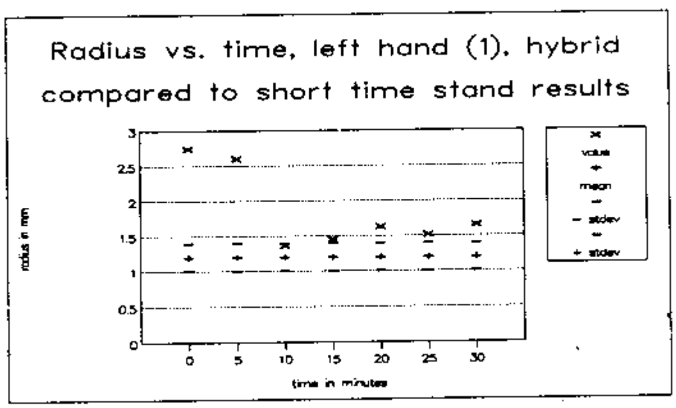


Figure 4. Speed results for all three trails compared to previous results mean and standard deviation.





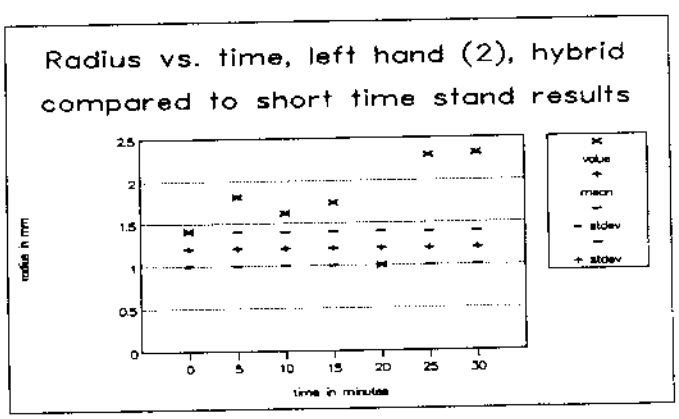
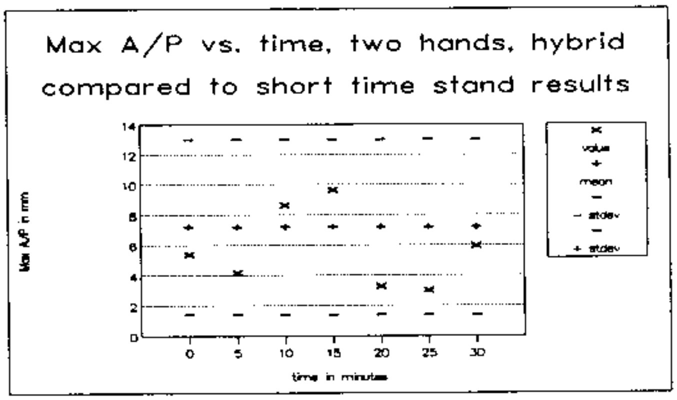
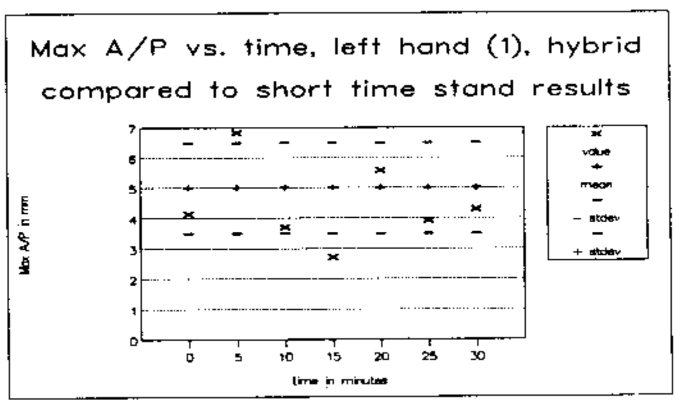


Figure 5. Radius results for all three trails compared to precvious results mean and standard deviation.





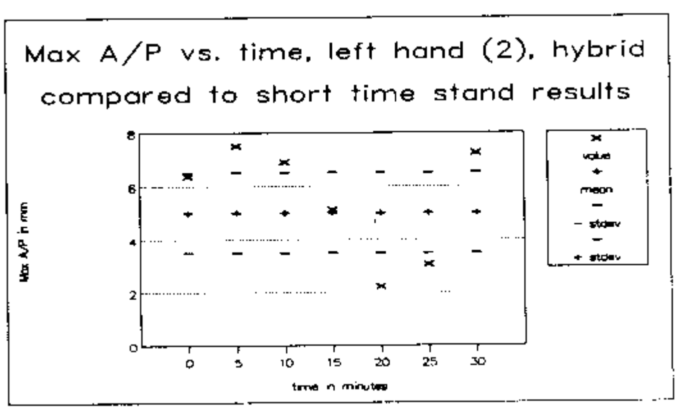
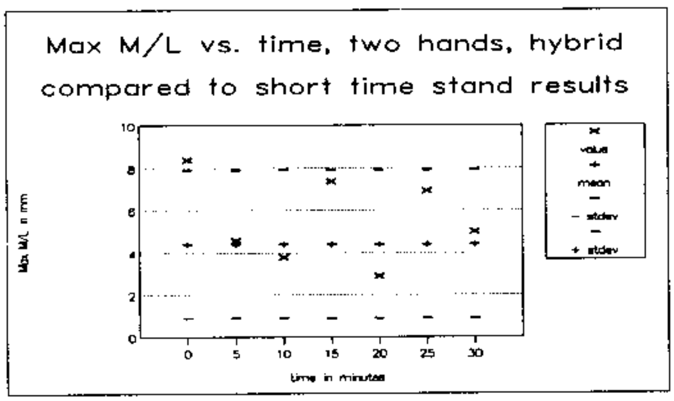
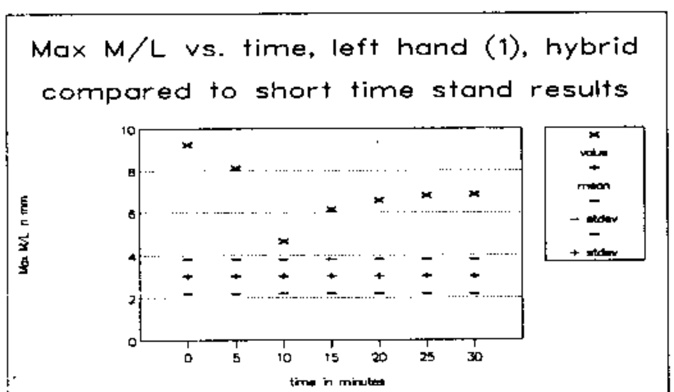


Figure 6. Maximum A/P dispalcement results for all three trails compared to previous results mean and standard deviation.





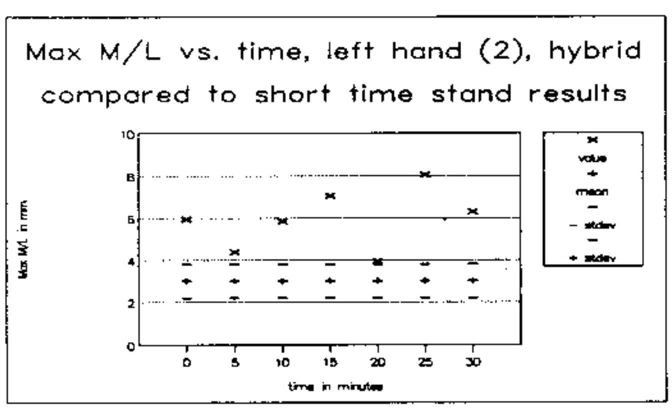


Figure 7. Maximum M/L displacement results for all three trails compared to previous results mean and standard deviation

	speed mm/s	radius mm	Max A/P mm	Max M/L mm
Two hands				
mean	3.4	1.4	7.2	4.4
st. dev.	2.0	0.8	5.8	3.5
Left hand				
mean	2.5	1.2	5.0	3.0
st.dev.	0.1	0.2	1.5	0.8

Table 2. Means and standard deviations of the values found in previous tests under the same hand support conditions.

DISCUSSION

As can be seen from the result graphs, the resulting values for each of the parameters are quite consistent through time. It can be said that the subject is just as stable all through the 30 minutes of the test, either using his left hand for support or two hands for support.

The values found for each of the parameters for all three tests are very close, indicating that standing with both hands on the support and with only the left hand on the support is equivalent in terms of stability for this subject. Using only the left hand for support presents the added advantage of leaving the subject's dominant hand free to allow him to do various tasks with it.

Using this system, the subject remains well within a limit of the mean plus minus two standard deviations of the previous results for the entire 30 minutes of the test. The cases where he does not -- both attempts with left hand for speed, radius and maximum M/L displacement-- an improvement over the previous values is observed in the form of the reduction in all these values. This could be due to the fact that the subject had had more practice in the use of the system from the time the previous set of measurements were taken or to the fact that standing for a longer period of time allows the subject to settle down better and thus results in greater stability. This system is also practical for standing for short periods of time.

From the results found it can be expected that subjects will be able to stand for even longer periods of time using this hybrid orthosis. The present study was limited to 30 minutes to avoid discomfort to the subject. In the past the subject had used a spinal jacket for standing and successfully avoided the bouts of pain completely. In this study, the use of the jacket was discarded since it might affect the very sensitive measurements made.

The next step in the development of this hybrid system is to convert it into a portable system that can be used away from a laboratory environment, such as in the home. The system implemented has the added advantage of being easily adapted to the specific needs of other subjects because of the programmable stimulator used for its development.

The subject felt particularly safe standing in this system and expressed a marked interest in its further development, both from the functional and the cosmetic points of view.

Acknowledgements: We are grateful for the cooperation of the staff and patients of the West of Scotland Spinal Injuries Unit at Philipshill Hospital. This project was funded by the Scottish Home and Health Department.

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