Increasing trunk stiffness via FES in paraplegic subjects

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Abstract

The application of FES to muscles of the trunk has the potential to provide substantial benefits for paraplegic and tetraplegic people.

Improvements in activities of daily living for these patients could be achieved by providing better stability for the upper body through the stimulation of low-back muscles.

In this study, the effects of open-loop FES applied to the erector spinae were tested during sitting, in two paraplegic subjects.

In particular, the investigation was related to one of the hypotheses suggested by previous studies on balance strategies in able-bodied subjects: that a mere increase of trunk stiffness provides better trunk stability.

A special apparatus and a protocol for testing balance capabilities during sitting were proposed.

The test is based on the measurement of the kinematic response to an external perturbation, which consisted in an angular displacement of the base of support during sitting.

Such angular displacement was applied without temporal warning (although the direction of the upcoming displacement was declared well before its application), in order to avoid any preparatory contraction of muscles still undergoing voluntary control.

The results suggest that the increase in trunk stiffness which can be achieved with FES does not significantly change the level of external perturbation from which subjects can successfully recover.

1 Introduction

The lack of control of the trunk has heavy consequences on everyday life of paraplegic and tetraplegic subjects.

Activities such as manual reaching, grasping and handling, as well as transfer from a wheelchair and manoeuvres for pressure relief, are performed relying on the upper body structures to bear the load of the body.

This is a source of potential damage in the long term, as those structures are subject to abnormal loading.

Electrical stimulation of the muscles of the trunk could be helpful in all the dynamic situations mentioned above, and could also bring benefits in sitting posture.

In fact, paraplegic subjects often develop scoliosis and exhibit postural strategies which are quite different from those of the able-bodied population (see [1] and [2]).

In particular, they tend to assume a kyphotic lumbar posture that enables the centre of mass of the upper body to be moved forward.

Despite its potential advantages, only a few studies on FES applied to trunk muscles could be found in literature (see [3], [4] and [5]).

Only one previous study ([6]) had used surface electrodes.

Several factors make the topic quite difficult: the spine is a complex structure, and muscles around it have often multiple motor points, are difficult to reach via surface stimulation and their numerous lines of action change with the trunk position.

Theoretical modeling studies have shown that although the ligamentous lumbar spine is insufficiently stiff to support the weight of the upper body [7], postural stability can be achieved through constant muscle activation [8]. However, it has been shown that the neuromuscular control system uses far more sophisticated strategies than open-loop, continuous co-activation [9].

Previous studies on able-bodied subjects show that they contract several muscles of the lumbar region in preparation to a sudden load (e.g. [10],[11],[12]).

However, the specific role of some of such muscle contractions (often called anticipatory
postural adjustments) is still at the centre of scientific debate.

Some of these contractions may even be generated to increase the pressure in the abdominal cavity, rather than for actual flexion/extension or lateral bending.

One of the suggested explanations for these anticipatory postural adjustments is that increased trunk stiffness provides an enhancement in trunk stability.

This was the main hypotheses of this study, in which trunk control of paraplegic subjects was tested in two different conditions:

1) sitting, without any FES applied;
2) sitting with open loop FES applied to the trunk.

As the stimulation level was fixed (i.e. no feedback control was used), situation no.2 simply corresponded to a steady increase in trunk stiffness.

The aim of the study was to determine whether surface FES applied to the lumbar erector spinae could help paraplegic people to cope with external disturbances.

2 Methods

The effects of FES applied to the trunk was tested on two paraplegic subjects; their data are reported in table 1:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age(years)</th>
<th>Height(m)</th>
<th>Weight(Kg)</th>
<th>Level of injury</th>
<th>Years post injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>M</td>
<td>26</td>
<td>1.90</td>
<td>87</td>
<td>T5</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>M</td>
<td>27</td>
<td>1.80</td>
<td>90</td>
<td>T3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1

A special apparatus was built in order to test the ability of the subjects to cope with external disturbances during sitting.

It consisted in a seat hinged on a bulky base, so that it could be inclined on the frontal or sagittal plane (only one direction at a time was possible). In order to provide some mechanical support, the seat was equipped with a low back rest and a belt. The external perturbation consisted in a sudden tilt of the seat on one side, delivered manually by an operator pushing or pulling a handle directly attached to the seat.

The operator could not be seen by the subject, so that no postural adjustment of muscles still under voluntary support could be made before the perturbation. The same operator was employed in all trials.

The travel of the handle was limited by adjustable pins, so that the angular displacement imposed by the perturbation had a precise value, measurable in degrees.

During the tests, both the seat angle and the trunk angle were measured, with a sample frequency of 50Hz.

Trunk angle was measured with an electrogoniometer, whose rigid endings were taped to the skin of the subjects over the spinous processes of T4 and L2.

To ensure a safe environment during the experiments, handbars were provided for the patients to catch themselves if needed, and an operator was always on site to prevent accidental falling.

The comparison of the trunk stability in the two situations (with or without stimulation) was based on the maximum angular amplitude of the tilt seat that a subject could cope with without failing. Failure in balancing was considered to occur when, as a consequence of the sudden tilt of the seat, the trunk angle exceeded 30 degrees. Generally, if this threshold was reached, the subject had to use his arms to catch himself on the handgrips, or the operator’s intervention was required. This protocol was approved by the local research ethics board.

In the trials involving the use of FES, this was delivered via surface electrodes placed on the skin to stimulate the erector spinae muscle group. The stimulation signal was a train of pulses at 30 Hz, pulse width 180 µsec and the amperage was adjustable from 0 to 100 mA.

3 Results

The results for the two subjects are shown in table 2 and 3 respectively, where the maximum tilt angle which would not induce balance failure (as previously defined) in the four directions are reported.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Without FES</th>
<th>With FES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left (deg)</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Right (deg)</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Anterior (deg)</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Posterior (deg)</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 2: Maximum perturbation angle before failure for subject A
4 Discussion and Conclusion

The results of this study do not support the initial hypotheses: the increase of trunk stiffness achieved with the stimulation does not result, in general, in an increase of the trunk balance.

The only real improvement has been registered for subject A, who could cope with a disturbance of significantly greater amplitude (7 degrees) when the FES was applied.

The initial hypotheses, however, is not rejected either: this could be due to insufficient muscle-force generated by the stimulation, or to inappropriate test procedure.

It remains unclear if a continuous, open-loop control strategy is appropriate for stabilizing the lumbar spine, or if a more intelligent, dynamic closed-loop scheme, as observed in able-bodied subjects, is required [9].

The test procedure seemed to be adequate to show the anisotropic characteristic of the trunk stiffness: for angular perturbations on the sagittal plane, a tilt backward is easier to deal with than a forward one.

However, this may in part be due to the design of the seat, which was equipped with a small backrest.

The initial conditions (i.e. the initial angle of the trunk with respect to the direction of the gravity force) may also play an important role in setting the maximum tilt angle before failure.

On the frontal plane, on the contrary, the performance is almost symmetrical: small differences of 2 degrees may not have great significance and could be due to a scoliotic posture.

This preliminary study should be followed by deeper investigations on the achievements which could be expected from the stimulation of the trunk muscles, which still remain unknown.

In particular, the role of training and the application of the FES to other muscles should be the next topics of research.

It must be determined if surface FES is capable of generating sufficient muscle contractions to stabilize the lumbar spine.

References


