Flexor spasms observed in a paraplegic during FES-assisted standing
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Abstract
The spinal cord injured population is a group that has a high incidence of spasticity. Though their spasms can occur spontaneously, they are often aggravated by internal and external stimuli. Functional activities, including those elicited by FES, can therefore be affected. This paper reports on a paraplegic that uses FES for standing, but whose quality of stand is complicated by an interesting pattern of flexor spasms. These occur after a period of spasm free standing and repeat at regular intervals, getting progressively worse. Whether this effect is dependent upon the stimulation, as EMG recordings suggest, but as yet not proven, or upon the varied and complex nature of spasticity, it conjures up issues both in identifying more robust controllers to deal with spasticity patterns and in selecting appropriate individuals.

1. Introduction
Spasticity has been defined as ‘a motor disorder characterised by a velocity dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome’ [1]. From a clinical perspective, spasticity is an important factor in the rehabilitation of patients with neurological conditions and, if severe, can significantly affect the individual’s quality of life by interfering with functional activities and behaviour. Spinal cord injured (SCI) persons have a high incidence of spasticity. Though they can occur spontaneously, spasms are often aggravated by internal and external stimuli; such as an infection, anxiety, temperature and touch. However, in our experience most SCI individuals have an understanding of the triggers for their spasms.

Standing is encouraged in paraplegics for physiological and psychological benefits and can be used to reduce flexor tone and encourage extensor activity [2]. One approach to assist in standing is electrical stimulation of the paralysed quadriceps muscles thereby generating knee extension to allow weight bearing through the legs. This technique has been successful, but to provide safe standing issues around the maintenance of balance, including during spasms, need to be addressed. Closed-loop controllers that respond to changes in the stand have therefore been advocated (see [3]). We are also interested in the types of disturbances that will be encountered.

This paper reports on a paraplegic who has achieved competent FES-assisted standing, but whose quality of stand is complicated by an interesting pattern of spasms. Spasms occur at the beginning of each stand, but these soon diminish allowing a spasm free stand. This in itself is not uncommon, because changes in muscle lengths, such as in standing up, can initiate responses [4]. The interesting observation is that within two minutes, flexor spasms occur that repeat at regular intervals of several seconds and in the absence of any known noxious stimuli. These spasms are found to get progressively worse and limit standing times to just a few minutes. This paper discusses these observed patterns.

2. Methods
2.1. Participant Details
The individual sustained a crush injury in 1994 resulting in a complete spinal cord lesion (T10 right, T11 left). Following rehabilitation, he achieved competent standing in calipers and in a standing frame, with minimal spasm activity on sit-to-stand. In 1996 he received an implanted sacral root bladder stimulator [5] – trapping bilateral anterior roots S2-S4 in intrathecal electrodes, accompanied by a bilateral posterior rhizotomy of roots S2-S5. Immediately following this procedure there was a marked increase in the severity of spasms and the number of triggers. Their effect was to cause him to discontinue using calipers. Baclofen is used to reduce lower limb and abdominal muscle spasms.

While participating on a FES-assisted standing programme [6], he demonstrated the ability to stand competently and to balance using a single arm for support. However, during these stands he experiences a series of
spasms that are remarkably consistent. Following a period of approximately two minutes standing with no spasms, hip and trunk flexion spasms subsequently occur, figure 1, and repeat every 16 seconds.

Fig. 1; Standing in the presence of flexor spasms

2.2. Measurement Methods
The approach taken to investigate the observed spastic patterns and their implications to the biomechanics in standing has been to measure the kinematics and reaction vectors, at the floor and handles, while recording EMG. During each test, the individual stands on a pair of Kistler force plates (Kistler Instruments AG Winterthur, Switzerland) and uses instrumented handles [7] for support. A dynamic position measuring system, Selspot (Selspot AB, Sweden), is used to record the individual’s posture in 3D space. Data is sampled at 50 Hz and analysed using MATLAB (The Math Works Inc, Natick, Mass., U.S.A.). EMG signals are recorded from quadriceps, hamstrings, gastrocnemius and tibialis anterior, and sampled at 1 kHz.

3. Results
Anecdotal evidence from the participant suggests that he is aware of the impending spasm before it has a resulting effect on his posture. This is supported by the video record that illustrates him “bracing himself”, extending his elbows and taking increased weight through his arms. In the periods between spasms, the arms are only used for balance and carry a small force, estimated to be approximately equal to the mass of the arms.

During a spasm, figure 2, the reaction forces demonstrate the increased proportion of the body weight (approximately 70%) taken through the arms. The ground reaction vector, in this case, passes significantly behind the knee and in front of the hip - both resulting in flexion moments. He attempts to correct this by applying a lateral downward push to maintain standing and to assist in correcting the hip flexion.

Fig. 2; Snapshot of biomechanical data during a spasm

Regarding each occasion where the individual flexes at the waist as a single spasm, the rhythmic nature has a period of approximately 16 seconds, figure 3. These continue for the rest of stand. Between spasms, the knee and hip angles remain relatively stable and the forces are taken again predominantly through the legs. This supports the clinical observation that an upright standing posture can be regained.

Fig. 3; Reaction forces and EMG recorded during FES-assisted standing

From the EMG recordings, there is a clear increase in activity in non-stimulated muscles, for example the hamstrings, for the duration of the clinically observed spasm, figure 3. In the stimulated quadriceps muscle, EMG recordings indicate a short latency reflex component
that starts as the spasm is elicited, but outlasts the clinically observed spasm, figure 4.

Fig. 4; M-wave and reflex in quadriceps for a single spasm.

4. Discussion
This individual demonstrates a peculiar result in his rhythmic pattern of flexor spasms while standing. At present we cannot determine if the SARSI procedure had a direct effect on the rhythmic pattern, or why it resulted in such a dramatic alteration in spasms. An increase in spasms following SARSI has been reported elsewhere [5], but these are not usually as severe as reported here.

It is not unusual for spasms to be generated in relation to noxious stimuli. With the same individual, the same pattern of flexor spasms was observed while palpating the metatarsal heads, an effect described elsewhere [4]; with S1 nociceptive stimulation of the foot generating L5 knee flexor, L2 hip flexor and T10 abdominal muscle contraction in a paraplegic. It is possible that in standing the same responses could be triggered by some stimulus, but from video the spasm occurrence is not correlated with any observed change in posture. It is also unusual that the spasms occur mid stand, after a minute or two of spasm free standing, and have an inter-spasm interval of approximately 16 seconds. The cause is not known, but the effect from applying a train of electrical impulses to stimulate the muscle could be acting to influence remaining neural circuits.

From an engineering perspective, these spasms present a difficulty in applying a suitable controller to assist in standing. From clinical experience [6], optimising a controller can be time-consuming and empirical, particularly in the presence of complex and varied spasticity. Generally, spasms result in fast transients in joint angles and using a controller to respond, by altering stimulation levels, may initiate further spasms resulting in instability and increased fatigue, particularly if the levels are caused to change too fast. The design of clinically more robust controllers should therefore try and accommodate for the often varied and complex nature of spasms and spasticity.

5. Conclusion
It is interesting to note that this individual continues to stand at home by FES. It is unknown as to whether we can improve his quality of standing, but we consider that an increased emphasis should be attached to identifying more robust controllers to deal with spasms. This may however, be complicated by its varied nature and complexity, raising issues not only in defining controllers, but also in selecting appropriate individuals and neuroprostheses. In addition and perhaps with this, a better understanding of the functional capacity of the residual nervous system and the effects of stimulation upon it is required.

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