Muscle activation patterns during transfers in individuals with spinal cord injury

Garry Allison
Kevin Singer
Robert Marshall

The utility of functional electrical stimulation regimens depend on an understanding of movement strategies and muscle activation patterns. The purpose of this study was to describe the electromyographic (EMG) profiles of the lateral transfer in individuals with spinal cord injury. Two movement strategy groups were examined: translatory (n = 9) and rotatory (n = 4). Transfer event markers were identified from force platform data. EMG signal profiles (100ms Root Mean Square envelopes) of triceps and latissimus dorsi bilaterally were generated for each group. Rotatory movement strategy demonstrates greater muscle synchronisation than do individuals who translate. The results provide evidence of different phasic characteristics of muscle activity during the lateral transfer using two possible movement strategies. The implications for intervention regimens are discussed.

Quadriplegia is a condition affecting all four limbs, which is invariably caused by a high level lesion of the spinal cord. It is a significant life threatening incident which has major motor, sensory and psychosocial consequences (Bromley 1986). The ability of patients with quadriplegia to perform simple transfers successfully is a major rehabilitation goal. The ability to transfer allows the individual to reach functional independence during activities of daily living (ADL) with increased opportunities for social interaction outside the rehabilitation institution (Bromley 1986, Norris-Baker et al 1981).

The most common transfer technique is the sitting transfer where an individual transfers laterally from one surface to another while in a sitting posture. In wheelchair users, it has been estimated that about 70 per cent of all transfers are of this type (Platts 1971) and, in paraplegic wheelchair users, an average of 14 to 18 transfers are performed each day (Pentland 1992). Transfers are a major component of functional indices associated with mobility and independence of individuals with quadriplegia (Gresham et al 1986).

The ability to transfer, in the individual with quadriplegia, is related to the ability to lift the body clear of a supporting surface (Bergstrom et al 1985), although some individuals are able to transfer with little clearance using sliding boards (Kogel et al 1981). This is particularly true for individuals with weak elbow extension.

Furthermore, it has recently been reported that at least two movement strategies may be employed when attempting to transfer (Allison et al in press). The first is translatory, where the movement of the head and pelvis occur in the same direction. The second is rotatory, where the head and pelvis move in opposite directions.

Irrespective of the movement strategy adopted by the individual, rehabilitation following quadriplegia is complicated, long-term and varied according to the level of the lesion and neurological deficits, and may involve many health professionals, techniques and modalities (Ford et al 1987, Hill 1986, Nixon 1985, Schneider 1985).

There are few direct interventions to improve specifically the ability to transfer in individuals with quadriplegia. Increasing the strength of the elbow extensors using posterior deltoid muscle transfer (Gellman 1991, Moberg 1975 and 1990) and functional electrical stimulation (FES) training of the triceps muscle (Seeger et al 1989) have yet to be shown to improve the ability to transfer.

Functional electrical stimulation for standing and gait in individuals with SCI has been widely reported in the literature (Kralj et al 1989, Phillips 1991). Such programs are based on the analysis of the muscle activity derived from electromyography (EMG) signal profiles and biomechanical models of normal movement patterns. Similar analyses are yet to be established for the lateral transfer in individuals with spinal cord injury (SCI). Therefore the
From Page 169

analysis of muscle activity during the transfer may provide fundamental information for future interventions such as FES.

Electrical stimulation may provide improved function when the method of muscle stimulation replicates the muscle activity pattern of the functional task. This is achieved by establishing the phasic or temporal changes in amplitude of the muscle activity during the functional task. For example, a neuroprosthesis for prehension has been utilised to improve function by replicating the functional muscle actions (Keith et al 1988). Similarly, the phasic characteristics of the EMG signal during stationary cycling have been used as the basis for synchronisation of muscles during electrical stimulation training programs with SCI individuals (Phillips 1991).

The phasic EMG signal characteristics of muscles used during the lateral transfer have yet to be reported. However, it would seem that such information may indicate recruitment strategies of the respective muscles during a transfer which would serve to develop any FES based interventions.

Factors which predict the ability to transfer have yet to be fully elucidated. However, it is generally accepted that patients with quadriplegia must learn to use skills of momentum and leverage, and re-learn kinaesthetic awareness, in order to achieve mobility in bed and the ability to transfer (Buchanan et al 1987, Schneider 1985). It is clear that the optimal performance of an individual with SCI is dependent on the selection of specific movement strategies and these in turn are dependent on the physical attributes that remain following the injury. A main focus on the ability to transfer has been associated with elbow extension strength. For example, Welch et al (1986) reported that the strength of the triceps brachii muscles is critical in predicting the ability of a quadriplegic patient to transfer whilst in the long sitting position. However, this does not quantify the amount of force required to transfer, nor does it account for patients who can transfer without a functioning triceps brachii (McGee et al 1977). Therefore the physiotherapist must use varied rehabilitation techniques to achieve success (Ford et al 1987, Kogel et al 1981, Schneider 1985). The idea of using FES with individuals with SCI to assist in their functional mobility is not new. However, the use of FES for the lateral transfer is limited by poor understanding of the task, and more specifically the muscle activity during the transfer.

Individuals with SCI also learn to modify their motor behaviour to best suit their physical capacities. For example, during rehabilitation many individuals with quadriplegia at the C5 and C6 levels learn to substitute muscles for specific actions and to maximise angular momentum and moment arms. The use of a rotatory strategy involving the alternate movement of the head and hips has been identified as a possible significant factor in the relearning of motor patterns by individuals with higher level SCI (Allison et al in press). In comparison, individuals with lower lesions and stronger elbow extension are able to utilise these muscles as prime movers and consequently perform a translatory movement pattern when transferring (Nixon 1985, Somers 1992). The EMG signal profiles of the different movement behaviours have yet to be reported.

The purpose of this study was to examine the phasic characteristics and the level of synchronisation between the elbow extensors and shoulder depressors during the lateral transfer in individuals with SCI who perform either a rotatory or translatory movement pattern.

**Methods**

**Subject recruitment**

From a larger study of the motion analysis of the lateral transfer in individuals with SCI, 13 subjects were identified as performing one of two movement strategies. Nine subjects used a translatory movement pattern and four subjects utilised a rotatory

---

**Figure 1.**

Schematic representation of the two movement strategies for the lateral transfer in individuals with SCI as viewed from the P-A perspective. A - translatory where the head and pelvis move in the same direction, B - rotatory where the head and pelvis move in opposite directions (Adapted from Allison et al in press).
pattern. The classifications of the movement patterns have been previously defined (Allison et al in press) and are schematically described in Figure 1. All subjects were male volunteers who provided informed consent and had motor complete injuries (Frankel Grade A, B and C, Frankel et al 1969). Gender was not an inclusion criteria. Subjects were included if they used a wheelchair for functional mobility tasks, were able to sustain a long sitting position safely and independently, were willing and able to sit on a hard surface for a period of 10 minutes and had been discharged as an inpatient from their rehabilitation institution.

Subjects were excluded from the study if they were:

i) individuals who had concomitant head injuries and/or neurological deficits associated with movement disorders;

ii) individuals who had neurological or musculoskeletal disorders prior to or independently of the spinal cord injury; or

iii) individuals with respiratory distress or illness, decubitus ulcers or upper limb pain that affected their functional mobility.

Ethical clearance was obtained from The University of Western Australia and Curtin University of Technology. Apart from the availability of a taxi voucher for those who did not have their own transport, no financial assistance or inducements were provided.

**Equipment**

Two EMG amplifier systems were used in this study. The first was a Grass® instruments amplifier with a Grass® regulated power supply. The second was a preamplified system with an Oxford Metrics® interface unit and Motion Control® preamplifiers. The preamplifiers had a common mode rejection rate between 102 and 104 dB for frequencies between 60 and 1000 Hz, 3 decibel cut-off bandwidth at 8Hz and 36kHz, a 1MΩ DC input impedance and a gain of 313 at 500Hz.

Assessment of the lateral transfer

Each subject was directed, when signalled, to transfer with his normal technique and pace, using only one movement. For this study, all subjects transferred to their left.

Both preamplified and normal electrodes were used in the study. In either case, the electrodes were placed bilaterally on latissimus dorsi as it reflects laterally around the inferior angle of the scapula and the longitudinal fibres of the long head of triceps brachii. Palpation of the muscle bellies was performed with voluntary resisted muscle action. When the manual muscle testing demonstrated a weakness, the electrodes were carefully placed over the muscle by palpation and the use of anatomical landmarks.

When preamplified electrodes were not used, 3M Ag/AgCl disposable electrodes were used at an inter-electrode distance of 20mm. A bipolar configuration with a common earth electrode on the acromion process was used and the skin prepared to maintain skin impedance less than 5kΩ. The differential amplifiers used in this study were high impedance of greater than 1MΩ with high pass and low pass cut-off frequencies set at 3Hz and 1000Hz respectively.
From Page 171

performed more than one distinct movement or made more than one attempt.

The transfer was performed in the long sitting position using two force platforms as the supporting surfaces. The force platform data were used to establish event markers for the lateral transfer. These were used for the synchronisation and time normalisation of the trials to establish mean EMG signal profiles. The start of the dynamic phase of the transfer (T1) was defined as the time when the Centre of Pressure (COP) was displaced 2cm from the static pre-transfer position. The finish of the dynamic phase of the transfer (T2) was defined by the peak vertical (Fz) force which was associated with the placement of the pelvis onto the supporting surface. The EMG signal data were collected during a period before, during and after the dynamic phase. The beginning of the data collection (T0) and the end of the data collection (T3) were defined as one third of the duration of the dynamic phase of the transfer (Figure 2).

Data reduction

Three trials were recorded at 500Hz. The data were initially demeaned and full wave rectified. Digital filtering was performed on the EMG data to attenuate the amplitude of signals with frequencies below 6Hz using a fourth order zero-phase lag Butterworth digital filter (Winter 1990). These data were then smoothed using a Root Mean Square (RMS) over 100ms. This provided a linear envelope of the EMG signal.

Amplitude normalisation

It is recognised that assessment of the muscle activity using the EMG signal during functional tasks is related to the type of muscle action that is performed (Allison et al 1993). Amplitude normalisation using maximal voluntary isometric contractions in general increases the variance in the grouped data. Moreover, attempting maximal contractions in the muscles crossing the shoulder girdle in the SCI population may compromise the safety of the individuals and, if not, presents as a logistic dilemma in the clinical setting. As the purpose of this study was to determine the relative muscle activity over time (phasic characteristics) of the identified muscles, the mean RMS of the ensemble (trial) average was used to normalise each EMG signal linear envelop.

The amplitude normalised EMG signal linear envelopes were time normalised to 100 data points during the dynamic phase of the transfer and 33 data points before and after this period. The mean and standard deviation for each of the 166 data points were calculated for each movement strategy group. The highest amplitude of the mean EMG signal was defined as peak muscle activity. The standard deviation was representative of the variation of the time normalised EMG signal between individuals.

Results

Table 1 describes mean and standard deviation of the sample population, lesion level, age, weight and years since injury.

![Figure 3](image-url)

Figure 3. Mean and one standard deviation above the mean of the EMG signal during a lateral transfer to the left for the triceps and latissimus dorsi bilaterally. A. Subjects who performed the translatory movement pattern (n = 9). B. Subjects who performed the rotatory movement pattern (n = 4). The data have been amplitude normalised to ensemble mean RMS (100ms), and the dynamic phase time normalised to 100 data points. Indicates the peak activity during the dynamic phase.
Table 1.
The mean and standard deviations for age, weight and years since injury for total sample and subgroups.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Lesion level</th>
<th>Frankel Grade</th>
<th>Movement Pattern</th>
<th>Age (years)</th>
<th>Yrs since injury (years)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C5</td>
<td>B</td>
<td>Rotatory</td>
<td>25.9</td>
<td>5.8</td>
<td>66.6</td>
</tr>
<tr>
<td>2</td>
<td>C6</td>
<td>A</td>
<td>Rotatory</td>
<td>31.7</td>
<td>5.9</td>
<td>65.5</td>
</tr>
<tr>
<td>3</td>
<td>C6</td>
<td>B</td>
<td>Rotatory</td>
<td>32.6</td>
<td>5.9</td>
<td>71.5</td>
</tr>
<tr>
<td>4</td>
<td>C7</td>
<td>B</td>
<td>Rotatory</td>
<td>22.1</td>
<td>0.9</td>
<td>72.7</td>
</tr>
<tr>
<td>5</td>
<td>C7</td>
<td>A</td>
<td>Translatory</td>
<td>24.6</td>
<td>5.2</td>
<td>51.8</td>
</tr>
<tr>
<td>6</td>
<td>C7</td>
<td>B</td>
<td>Translatory</td>
<td>21.5</td>
<td>2.6</td>
<td>64.1</td>
</tr>
<tr>
<td>7</td>
<td>C8</td>
<td>B</td>
<td>Translatory</td>
<td>49.2</td>
<td>32.4</td>
<td>71.8</td>
</tr>
<tr>
<td>8</td>
<td>C8</td>
<td>B</td>
<td>Translatory</td>
<td>38.9</td>
<td>9.4</td>
<td>59.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Quadruplegic mean (SD) n = 8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>T2</td>
<td>A</td>
<td>Translatory</td>
<td>22.1</td>
<td>4.6</td>
<td>50.9</td>
</tr>
<tr>
<td>10</td>
<td>T5</td>
<td>A</td>
<td>Translatory</td>
<td>33.9</td>
<td>9.4</td>
<td>60.6</td>
</tr>
<tr>
<td>11</td>
<td>T10</td>
<td>A</td>
<td>Translatory</td>
<td>40.6</td>
<td>16.9</td>
<td>77.0</td>
</tr>
<tr>
<td>12</td>
<td>RtT7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lt T11</td>
<td>B</td>
<td>Translatory</td>
<td>35.2</td>
<td>35.2</td>
<td>49.9</td>
</tr>
<tr>
<td>13</td>
<td>Rt L1</td>
<td>C</td>
<td>Translatory</td>
<td>33.7</td>
<td>16.9</td>
<td>66.6</td>
</tr>
<tr>
<td></td>
<td>Lt C.Equ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paraplegic mean (SD) n = 5</td>
<td></td>
<td></td>
<td></td>
<td>33.1 (6.8)</td>
<td>16.6 (11.6)</td>
<td>61.0 (11.3)</td>
</tr>
<tr>
<td>Total mean (SD) n = 13</td>
<td></td>
<td></td>
<td></td>
<td>33.1 (6.8)</td>
<td>16.6 (11.6)</td>
<td>63.7 (8.8)</td>
</tr>
</tbody>
</table>

C.Equ - Cord equinae lesion.

Frankel grades A - complete motor and sensory, B - Complete motor with some sensory sparing, C - motor incomplete yet functionally 'useless'. (Frankel et al 1969)

Figure 3 shows the EMG signal templates of the four muscles tested during the lateral transfer. The right and left are defined as viewed from behind. All subjects transferred to their left (see Figure 1). These templates show the mean and one standard deviation above the mean of the nine subjects who performed the translatory movement pattern (Figure 3A) and four subjects who performed the rotatory movement pattern (Figure 3B). The data were time normalised with the dynamic phase of the transfer (shaded) representing 100 data points.

Figure 3 also illustrates the peak activity of the average EMG signal for all muscles during the transfer. During the translatory movement strategy, the right triceps and latissimus dorsi reached peak activity in the first 25 per cent of the dynamic phase of the transfer. In the corresponding left sided muscles, peak activity occurred at approximately 75 per cent of the time normalised transfer. In comparison, the rotatory transfer demonstrated that the peak activity of all the muscles occurred at approximately 60 per cent of the dynamic phase of the transfer.

The peak activity of both elbow extensors and the right latissimus dorsi appear to be synchronised. Therefore the degree of simultaneous peak activity of the muscles on each side of the body during the rotatory pattern is greater than those in the translatory pattern.

Discussion

EMG signal profiles were used to assess muscle activity during two patterns of lateral transfers performed...
From Page 173
by individuals with SCI. The findings suggest that phasic activity of the triceps and latissimus dorsi are not as definitive as the phasic nature of the lower extremity muscles during gait (Perry 1992). However, in both movement strategies there seems to be a level of simultaneous activation between the elbow extensors and the latissimus dorsi on the transfer (right) side. Indeed, both groups demonstrated increased muscle activity during the dynamic phase of the transfer, which would indicate that the event markers delineated the lifting phase of the transfer.

In individuals who performed the translatory movement pattern, the peak activity of the right triceps and left latissimus dorsi occurred at similar times during the first half of the dynamic phase of the transfer. The amplitude of the EMG signal then gradually decreased throughout the remaining phase of the transfer. The increased amplitude of the EMG signal at the early stage of the dynamic phase of the transfer may be associated with concentric muscle actions (Allison et al. 1993, Komi 1992, White et al. 1993). Therefore, the level of activity of these two muscles seems to be synchronised and indicates that they may be acting as prime movers or agonists. This is further supported by the fact that all the individuals who performed the translatory movement strategy had lesions at or below C7 and therefore had relatively strong triceps when compared with individuals with higher lesions. The left triceps and latissimus dorsi reached peak activity in the latter half of the dynamic phase of the transfer. However, the activity pattern of the left latissimus dorsi is less clear since there was little amplitude change in the average signal during the dynamic phase of the transfer. This may imply that the contracting muscle and the contraction, the action and velocity of the muscle during the dynamic phase of the transfer is minimal phasic responses or, if subjects demonstrated phasic responses, that there was little synchrony between subjects. In the latter case, the variation may reflect the diversity of motor behaviours of the individuals and/or the functional diversity of the muscle during the transfer, since the EMG signal amplitude may vary due to the load and the type of muscle activity (Komi et al. 1987, White et al. 1993).

Similarly, the left latissimus dorsi in individuals who transferred using the rotatory method was found to demonstrate minimal phasic characteristics. The motor pattern of the left latissimus dorsi (the placement arm) illustrates minimal phasic responses during the dynamic phase of the transfer, irrespective of the movement strategy adopted by the individual.

The time of the peak activity of the elbow extensors was different between the rotatory and translatory movement strategies. During the translatory movement strategy, the right triceps reached the peak activity in the first 25 per cent of the dynamic phase whereas the left triceps peaked in the last 25 per cent of the transfer. This unilateral synchronisation may reflect the function of the muscles acting as prime movers. Consequently, a bilateral synchronisation may be required to maximise the rigidity and rotation of the trunk. In summary, these findings demonstrate different muscle activity patterns during the two movement strategies when transferring.

Rehabilitation implications
The nine individuals who performed the translatory movement pattern had lesions at or below C7 (Frankel A, B or C). Consequently, they had relatively strong triceps and latissimus dorsi. The individuals who performed the rotatory pattern had higher lesions and had weakness in voluntary elbow extension. These two patterns imply that the movement strategy for any future FES interventions may vary and factors such as anthropometric parameters may influence the strategy selection best suited to the individual. Therefore this study supports the notion that motor learning and motor behaviours can not be overlooked during the rehabilitation phases, particularly if electrical stimulation programs are to be attempted (Buchanan et al. 1987, Ford et al. 1987, Schneider 1985).

The findings of this study raise another issue for physiotherapists considering a FES rehabilitation regimen, specifically the type of electrical stimulation protocol that may be attempted. Two approaches may be taken when using electrical stimulation to improve function. The first technique involves the use of electrical stimulation to replicate the muscle activation patterns which result in a near to normal muscle firing sequence. The second is a simpler approach which uses electrical stimulation as a method of assistance either to facilitate muscle function or, in conjunction with an assistive orthotic device, as a hybrid gait training system. In the context of this study, it would seem that to replicate a translatory movement pattern, at least two phases of stimulation are required, where the left and right sides are stimulated in sequence.

To replicate the rotatory strategy muscle function, all the muscles may be stimulated essentially simultaneously. However, the small sample size limits further generalisations. Nevertheless, the use of FES to assist transfers other than replicating the muscle activities found in this study is an issue for future research, particularly when considering possible hybrid/orthotic devices as in the FES-Reciprocal-Gait Orthosis (Phillips 1991).

The replication of muscle activity patterns, as in gait, requires stimulation control parameters which modulate the level of torque generated by the contracting muscle and minimise the effects of fatigue. Although the EMG signal profiles of this study provide some information as to the phasic responses of the muscle activity, further investigation of the magnitude of the muscle’s activity during the transfer is needed, since amplitude is dependent on the level of the contraction, the action and velocity of the muscle (White et al. 1993). In this study, both muscle groups acted...
across multiple joints, and it would seem that they may act in varying degrees as stabilisers as well as prime movers, according to the movement strategy. The left latissimus dorsi demonstrated minimal amplitude changes of the EMG signal during the transfer compared with the other muscles, irrespective of the movement strategy. Further analysis is required to elucidate the torque requirements and control parameters of a FES program to achieve a successful transfer movement pattern.

During the lateral transfer, fatigue induced by repetition may not be a major problem, since the task is of short duration. However, fatigue relative to the level of torque required may be critical. The reason for this is that the muscles targeted in FES training for transfers are likely to be partially innervated, since the zone of injury may affect the final common pathway of some of the motor units within the muscle. Therefore, the muscles may require maximal stimulation to generate sufficient torque for a transfer. Clearly, as demonstrated by FES gait programs, a strength training regimen would need to precede FES applications (Phillips 1991).

Moberg (1975) estimated the forces at the wrist required to achieve a transfer to be as small as 7kg. Although it is possible to generate significant elbow extension torques in normal muscles, there are three factors which need consideration during electrical stimulation interventions in individuals with quadriplegia. First, the final common pathway to the muscle must be intact (upper motor neurone lesion) to allow sufficient stimulation frequencies to generate significant torques. Secondly, it is yet to be demonstrated if an electrical stimulation training program can generate sufficient torques for a transfer in both triceps and latissimus dorsi. Finally, if the latissimus dorsi or, more importantly, the triceps brachii, can be stimulated to generate significant torques, then the zone of injury must be proximal to the innervation level of these muscles. In such cases it may be questionable if the voluntary muscle control at the shoulder girdle is sufficient to provide adequate proximal stability during transferring tasks, irrespective of the movement strategy. These issues remain unanswered.

Conclusions

This study demonstrates the phasic characteristics of four muscles in two groups of individuals with SCI who use different movement strategies when attempting to transfer. Relative synchronisation of the peak muscle activity during the dynamic phase of the transfer differs according to the movement strategy selected by the individual. These EMG signal templates may direct future biomechanical and kinematic research and development of rehabilitation intervention programs, such as FES, which could facilitate the ability to transfer in individuals with high to mid level quadriplegia.

Footnotes

† Grass Instrument Co., Model P511K, RPS 107C Quincy, MA USA.
¶ Motion Control, Division of IOMED Inc. Salt Lake City, Utah USA.

Acknowledgements

The authors would like to acknowledge the assistance provided by the technicians from The University of Western Australia Department of Human Movement.

References


