

MOVEMENT AND MUSCLE ACTIVITY PATTERN IN WHEELCHAIR AMBULATION BY PERSONS WITH PARA- AND TETRAPLEGIA

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ABSTRACT. The patterns of movement and muscle activation in wheelchair ambulation have been studied in two groups: subjects with paraplegia ($n=4$) and tetraplegia ($n=3$). All subjects were physically active and experienced wheelchair users. The tests were done in the subjects' own wheelchairs and under free-wheeling conditions. The tasks studied were: self-chosen normal velocity, maximal velocity and maximally accelerated start. Muscle activation was registered by surface electromyography performed on several arm and shoulder muscles. The movement pattern was studied by goniometry of the shoulder and elbow joints, as well as by observing video recordings. Speed and arm cycle frequency were also recorded. The movement pattern was divided into three phases: pull, push and recovery. Relatively concordant muscle activation patterns were noted within the groups, whereas differences were noted between the groups with regard to muscle activation, length of the pull and push phases and the velocity-dependent adaptation. The subjects with tetraplegia were more dependent on the pull phase. The self-chosen normal and maximal speeds of the subjects with tetraplegia were approximately half those of the subjects with paraplegia. Three different types of recovery movements were noted as well as a velocity-dependent adaptation. Major trunk movements during the rim phase were only noted at the maximally accelerated start. In conclusion, the results point to both similarities and differences in the movement pattern and muscle activation in individuals with para- and tetraplegia under different ambulation conditions. The differences are of such a magnitude that they are important enough to consider when teaching wheelchair techniques and developing rehabilitation programmes for different groups of patients with spinal cord injuries.

Key words: arm muscles; electromyography; movement pattern; paraplegia; shoulder muscles; tetraplegia; wheelchair propulsion.

INTRODUCTION

A good technique in wheelchair propulsion is of great importance to spinal cord injury victims in their daily lives, recreation and sports. A knowledge of movement and muscle activation patterns developed in connection with these injuries is also of value for rehabilitation with regard to both teaching technique and the development of more specific strength-training programmes.

It is apparent that the injury level is an important determinant in this respect. However, to our knowledge, no comparative study has been published hitherto on wheelchair technique under normal ambulation and wheelchair conditions for both persons with tetraplegia (T) and those with paraplegia (P) with long-standing injuries. Harburn & Spaulding (4) studied the muscle activation pattern in recently injured persons with P and T who did not use their own wheelchairs. The arm cycle frequency was set. Others have compared the propulsion techniques of persons with P and T sprinting in a wheelchair ergometer (3).

It has been demonstrated, however, that the wheelchair conditions imposed (e.g. sitting positions, stroke frequencies and ergometer versus free-wheeling wheelchairs) affect the activation of muscles, mechanical efficiency and propulsive forces (6, 12, 17). Furthermore, it has been shown that both the mechanical efficiency (2) and the movement pattern (2, 15) may differ between able-bodied persons and wheelchair users. Thus, if the object is to study a more real-world situation, the experimental conditions should mimic it, and the specific group of interest should be studied.

A description of the pattern of movement and muscle

activation in persons with P and T is also of great interest in the search for explanations for recent findings of a considerably slower fibre type composition in a wheelchair-propelling muscle (anterior deltoid muscle) in individuals with T as compared to those with P (11).

It is reasonable to assume that physically active persons with P and T with old injuries and long experience of wheelchair dependency have acquired adequate muscle activation and movement patterns. Therefore, the aim of the present study was to monitor them during level free-wheeling propulsion. The subjects used their own wheelchairs, and three conditions were studied: self-chosen normal "everyday life" velocity, maximal velocity and maximally accelerated start.

METHODS

Subjects

Three male subjects with P, one female with P and three male subjects with T participated in the study. The handicaps were caused by traumatic injuries in all the male subjects, whereas the female subject was born with a malformation of the spinal cord. One of the subjects with T had retained brachial triceps muscle function. All of them were physically active and wheelchair-dependent and had a long experience of wheelchair ambulation. Data on the subjects are presented in Table I.

Anthropometric and wheelchair measurements

Arm length was measured as the distance between the greater tubercle of the humerus and the tip of the long finger when the arm was fully extended. The upper body length was measured as the distance between the acromion and the seat of the wheelchair. The hand position was determined in relation to the axis of rotation of the wheel under two conditions: (a) arm hanging down fully extended, and (b) arm hanging freely in a resting position. In the first case, the vertical distance between the axis of rotation of the wheel and the tip of the long finger was measured. The fingertips of all subjects were at or below the wheel axle. In the second case, the horizontal perpendicular distance between the wheel axle and the midpoint of the palm was measured. Wheel and rim diameters were also measured.

Electromyography

Muscles and electrodes. The electromyography (EMG) recordings were made on the right side of the body with surface electrodes on the brachial biceps and triceps, anterior and posterior deltoid, pectoralis major and trapezius muscles (Fig. 1). The surface electrodes used were Beckman miniature silver/silver chloride, diameter of pickup area 4 mm, with a fixed interelectrode distance of 8 mm.

Signal transferring and processing. A telemetry system (Medenik, Österbybruk, Sweden) was used for signal transferring. The surface electrodes and the electrogoniometers (cf. below) were connected to transmitters. The electromyographic and goniometer signals were transmitted to

Table I. Description of the subjects. Duration refers to years with injury.

The missing data on the female subject with paraplegia are due to the fact that she was unaware of her weight and that she was born with a malformation of the spinal cord

Subject	Sex	Age (yrs)	Weight (kg)	Duration (yrs)	Injury level
<i>With paraplegia</i>					
1.	M	34	52	30	T 9-10
2.	M	36	65	27	T 9
3.	M	22	80	2	T 11-12
4.	F	25	-	25	-
Mean		30	66	21	
<i>With tetraplegia</i>					
1.	M	33	58	15	C 5-6
2.	M	43	48	28	C 5-6
3.	M	25	67	4	C 6-7
Mean		34	58	16	

a receiver. All signals were amplified 3000 times and bandpass-filtered (10-1500 Hz) and displayed on a Mingograph 803 ink-writer with a straight frequency response up to a 1200 Hz (Siemens-Elema, Sweden).

Maximal voluntary contraction. For each muscle, a static maximal voluntary contraction (MVC) was recorded and used for reference (cf. below). The maximal efforts, chosen to be relevant to wheelchair ambulation, were made in the following positions against isometric external resistance by an investigator: the *brachial biceps* and *triceps* muscles—elbow flexion and extension, respectively, at an elbow flexion angle of 90°, holding the upper arm along the trunk, with external resistance applied distally to the lower arm. In the following three muscles, the external resistance was applied distally to the upper arm with the whole arm held straight: the *pectoralis major* muscle—a combination of flexion and adduction of the shoulder at a shoulder flexion angle of 45°, the *anterior deltoid* muscle—shoulder flexion (i.e. elevation forward) at a 45° angle, the *posterior deltoid* muscle—shoulder extension at a 45° angle. For the *trapezius* muscle, the external resistance was against a combination of elevation and extension of the whole shoulder.

Signal analyses. The onset and termination as well as the height of the peak amplitude for each muscle were determined by two investigators who made a joint decision based on visual inspection. The amplitude of the EMG signal was measured in millimetres at each MVC. During the various dynamic wheelchair tasks, the height of the peak amplitude was measured and further expressed as a percentage of the magnitude during the MVC for each subject and muscle. This was used as an indication of the degree of muscular activation.

Movement registration and analysis

The flexion and extension movements in shoulder and elbow joints were monitored using electrogoniometry. Both EMG and goniometer signals were transmitted wirelessly to a Mingograph (cf. above). All experiments were video-filmed with the subject in profile as a further basis for the movement analysis. This was

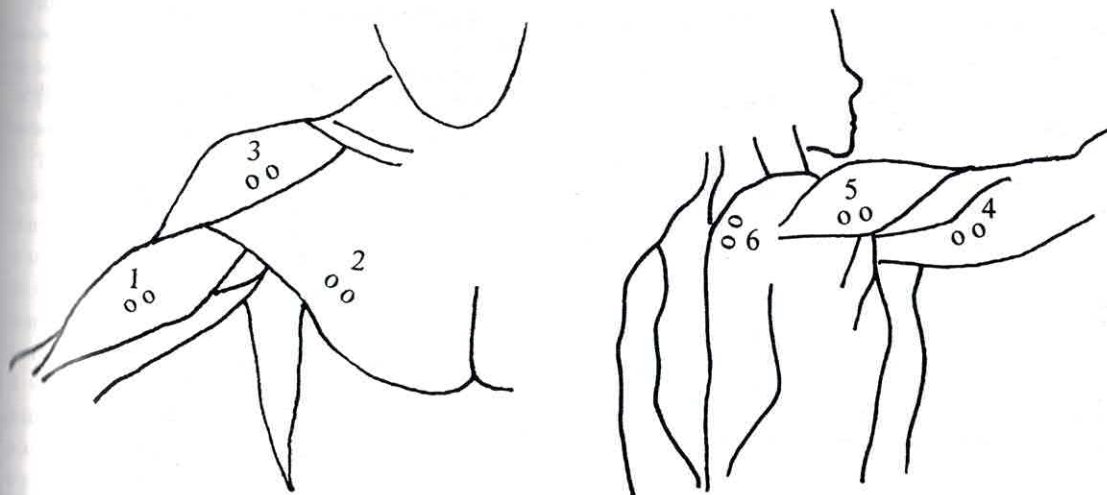


Fig. 1. The electrode placements on the (1) brachial biceps, (2) pectoralis major, (3) anterior deltoid, (4) brachial triceps, (5) posterior deltoid and (6) trapezius muscles.

done from a wheelchair moved in parallel with the subjects' wheelchairs. Recovery movements were described on the basis of hand movement. Trunk movements were analysed from video recordings, and based on the angle between the top dead centre (12 o'clock) of the rim and the posterior portion of the spinous process of the seventh cervical vertebra.

Experimental procedure

The study was conducted in a gymnasium with a wooden floor. Three conditions were studied: (a) the self-chosen, normal wheelchair velocity corresponding to "walking" for the able-bodied, (b) maximal velocity, and (c) a maximally accelerated start. The propulsion velocity and arm cycle frequency were also measured. The measurements are based on one successful trial in each task. Normally, this was attained at the first trial.

RESULTS

Anthropometric and wheelchair data

Data from anthropometric and wheelchair measurements are presented in Table II. In all subjects the wheel axle and the centre of the palms were aligned vertically when the hands were hanging freely in a relaxed position. With fully stretched arms, the fingertips generally reached a point about 5–10 cm below the wheel axle.

Velocity and arm-stroke frequency

The low speed, representative of everyday life, self-chosen normal ambulation, was 2.0 m/s for subjects with P and 1.1 m/s for those with T (Table III). The maximal

velocities were 4.3 and 2.4 m/s, respectively. The arm-stroke frequency at the low speed was 57 strokes/minute for subjects with P and 45 for those with T. The corresponding values at maximal speed were 99 and 83 strokes/minute.

Movement phases

The arm movements were divided into a rim phase and a recovery phase. The rim phase is defined as being when there is contact between the hand and the rim. The rim phase has been divided into a pull phase and a push phase, during which the elbow angle decreases and increases, respectively. The termination of the rim phase coincided with the peak flexion and extension of the shoulder and elbow joints, respectively.

Types of recovery movements

Three types of recovery movements were noted: (1) a movement with the hand along a path similar to that in the rim phase but in the opposite direction, a so-called "pumping movement" (2) a more "semicircular" movement with close to a straight line from the end to the starting-point of the rim phase, and (3) a movement creating a more or less circular or elliptic motion.

Movement and muscle activation patterns

Subjects with P, Fig. 2A. All four subjects displayed

Table II. Anthropometric and wheelchair data. For an explanation of the measurements, see Methods

Subject	Upper body length (cm)	Arm length (cm)	Hand position, vertical (cm)	Hand position, horizontal (cm)	Rim diameter (cm)	Wheel diameter (cm)
<i>With paraplegia</i>						
1.	45	78	18.5	0	54	60
2.	55	68	9	0	55.5	61.5
3.	50	67	0	0	54	60
4.	49	66	7	0	54	60
Mean	50	70	9	0	54	60
<i>With tetraplegia</i>						
1.	54	76	10	0	54	60
2.	53	77	8	0	54	60
3.	52	79	0	0	54	60
Mean	53	77	6	0	54	60

both pull and push phases during normal and maximal velocities, whereas during the maximal start, two subjects only displayed push phases. The changeover from the pull to the push phase always occurred at, or close to, the highest point on the rim (12 o'clock). With speed changes, the length of the phases shifted. When comparing the normal velocity with the maximal velocity and maximally accelerated start, a progressively shorter pull phase and a longer push phase were generally noted in the last two situations.

During normal velocity, the brachial biceps muscle was predominantly active during the pull phase, whereas the brachial triceps muscle was mainly active during the push phase. The major pectoral and anterior deltoid muscles were active during both the pull and the push phases. In the recovery phase, the posterior deltoid and trapezius muscles were distinctly active. These muscles could, however, also be involved in the other phases,

especially the trapezius muscle in the push phase. During maximal velocity and maximal start the involvement of the brachial biceps muscle was still essentially limited to the pull phase. The involvement of all other muscles was now observed in the push phase, in which they acted in a concordant manner. Regardless of the type of recovery movement (cf. below), the posterior deltoid and trapezius muscles in particular were active during part of, or the whole, recovery phase in all three measurements.

The peak EMG amplitude of every muscle studied was higher in the maximal speed and maximal start than at normal velocity. There were no major differences between the latter two situations, except a somewhat higher activity of the anterior deltoid muscle in the maximal start situation.

During the normal velocity, all recovery movements were of the circular or elliptic type, whereas the

Table III. Wheelchair propulsion characteristics. For an explanation of the measurements, see Methods

Subjects	Normal velocity m/s	Maximal velocity m/s	Normal velocity, arm cycle frequency cycles/min	Maximal velocity, arm cycle frequency cycles/min
<i>With paraplegia</i>				
1.	1.8	4.2	58	83
2.	2.1	4.1	71	136
3.	2.2	4.4	50	83
4.	2.0	4.4	50	94
Mean	2.0	4.3	57.2	99.0
<i>With tetraplegia</i>				
1.	1.0	2.0	52	88
2.	1.3	3.6	45	107
3.	0.9	1.7	39	55
Mean	1.1	2.4	45.3	83.3

"pumping" or semicircular movements were seen at the maximal velocity and maximal start. Regardless of the type of recovery movement, the posterior deltoid and trapezius muscles were active during part of, or the whole, recovery phase.

The trunk was in an upright position and no, or only minimal, movements ($< \approx 5^\circ$) in the trunk were observed during the normal velocity. At the maximal velocity, trunk movements of $5\text{--}15^\circ$ were noted in three subjects. In two of these subjects the position of the trunk at the starting-point was flexed ($\approx 15^\circ$). At the maximal start a trunk movement of $20\text{--}30^\circ$ was noted in all subjects, and it was initiated from a flexed position of $10\text{--}20^\circ$. This movement pattern persists during the first part of the acceleration phase and diminishes successively as a higher speed is attained. The interaction between the trunk and the arm movements at the maximal start can be described as a flexion of the trunk at the beginning of the rim phase and, at the same time, there is generally a minor flexion of the elbow. This is followed by an extension of the elbow and a concomitant extension of the trunk back to the starting position.

Subjects with T, Fig 2B. All subjects displayed both pull and push phases under all conditions studied. The changeover from the pull to the push phase always occurred at, or close to, the highest point on the rim (12 o'clock). The length of the phases shifted with speed changes. During maximal speed and maximal start, the pull phase was shorter than during normal speed, whereas only minor changes were related to the push phase.

Compared with those with P, subjects with T are relatively more dependent on their pull phase, during which the brachial biceps, anterior deltoid and pectoralis major muscles are active under all conditions studied. In addition, the brachial biceps muscle appeared, as judged from the duration of its activation, to play a greater role during the push phase than that seen in subjects with P. The duration of activation of the trapezius and posterior deltoid muscles is less marked during the rim phase in subjects with T than in those with P.

The peak EMG amplitude of every muscle studied was higher in the maximal speed and maximal start situations compared to the normal velocity, whereas it was of a similar magnitude in the two former situations.

During the normal velocity, all recovery movements were of the circular or elliptic type, whereas the "pumping" or semicircular movements were seen at the maximal velocity and maximal start. Regardless of the type of recovery movement, the posterior deltoid and

trapezius muscles were active during part of, or the whole, recovery phase in all three situations.

With regard to the trunk, no movements were noted during the normal velocity, whereas a small flexion-extension movement ($\approx 5^\circ$) was seen in one subject at the maximal velocity and in two subjects at the maximally accelerated start. The initial position of the trunk was always upright.

DISCUSSION

Movement phases

The pattern of movement during wheelchair ambulation has generally been divided into a propulsive phase or a push phase and a recovery phase (cf. 6, 7, 12). However, the propulsive phase or push phase may also include a "pull movement", as has been pointed out by Dallmeijer et al. (3). In our opinion, it is therefore more adequate to make a division into a pull phase and a push phase. This is not least apparent when studying individuals with T.

These terms imply a propulsive force being generated in the pull and/or push movements. It is therefore of interest to note that Sanderson & Sommer (9) pointed out that there may be times when there is contact between the hands and the rim but no application of force to increase or maintain the velocity of the wheelchair.

In order to distinguish clearly when an application of force leading to propulsion is initiated and terminated, other measuring techniques than those used in this study are required. However, the EMG activity of the major "propulsive" muscles can give an indication in this matter, and in the present study we noted that there were sometimes delays between hand contact and the EMG activity of these muscles. We have therefore used the more neutral term "rim phase" for the period when there is contact between the hand and the rim.

Several earlier studies have indicated rather large inter-individual differences in wheelchair movement patterns (e.g. 3, 9). This also applies to the present study, but common denominators could also be traced.

Differences in body dimensions and muscle force may explain part of the individual variation. One subject with P (subj. 1) illustrates this. He was a well-trained, elite sportsman in wheelchair competitions with a short upper body (45 cm) but long arms (78 cm) (cf. Table I). This facilitates longer pull and push phases as well as muscle activation periods, a possibility that the subject made use of under all conditions studied.

Although individual variation exists, the differences in

Subjects with paraplegia

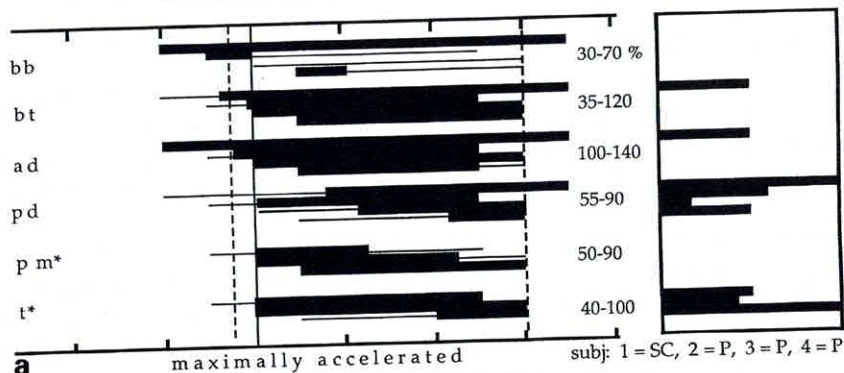
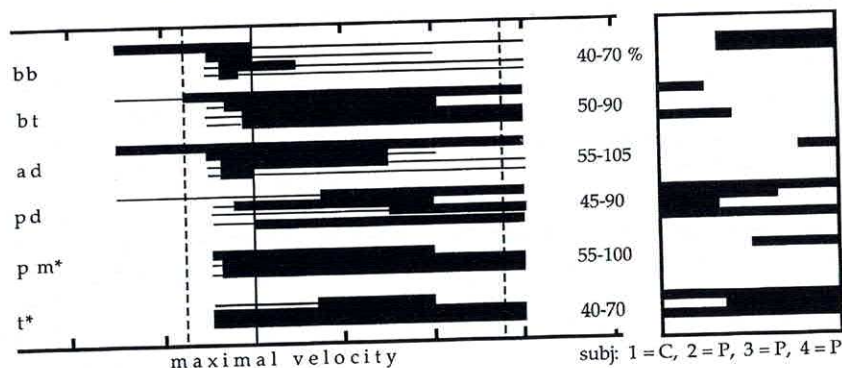
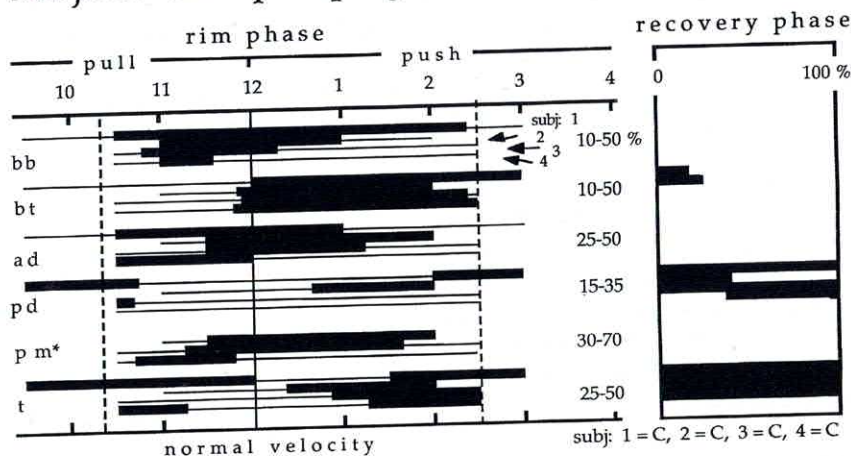
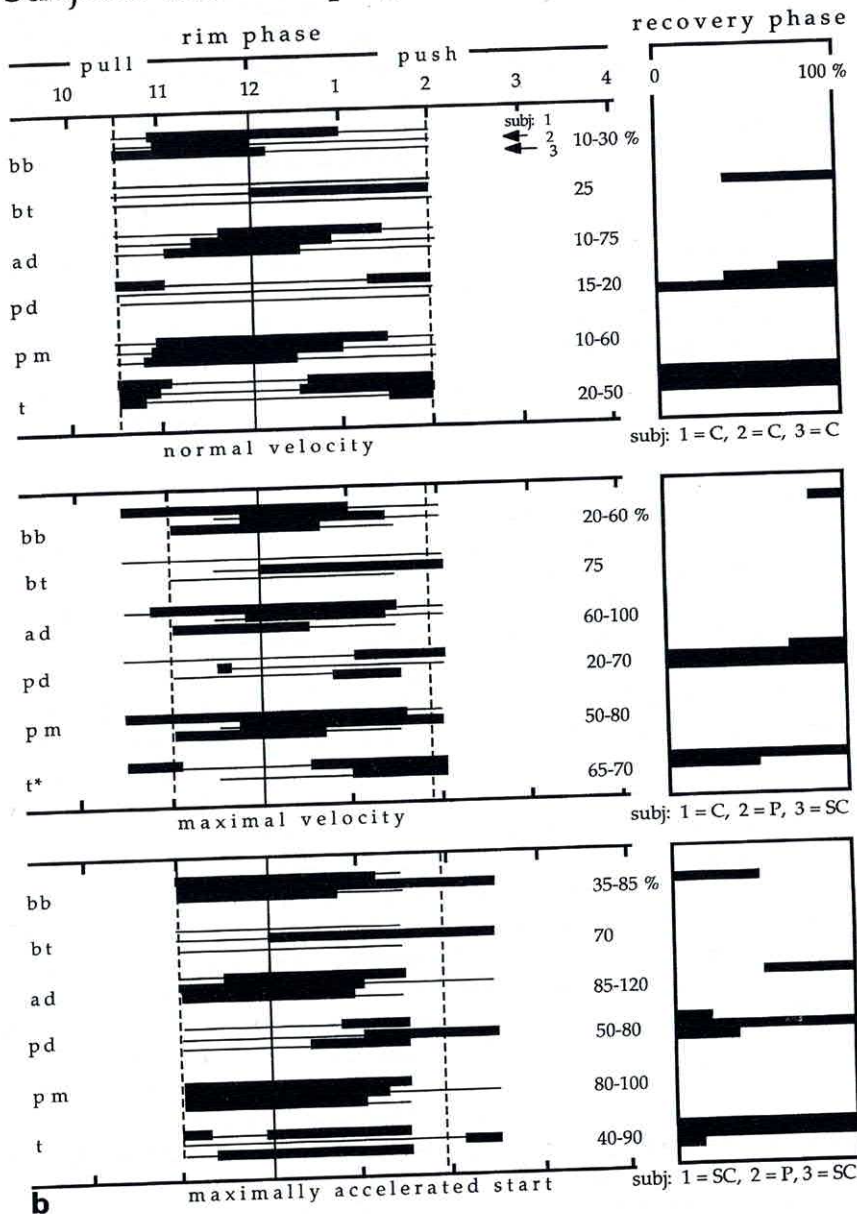


Fig. 2. The rim phase localization for the different subjects with paraplegia (A) and tetraplegia (B), its division into pull and push phases, the recovery phase and periods of muscle activation in wheelchair ambulation. The conditions studied were normal "everyday life" velocity, maximal velocity and maximally accelerated start. One of the subjects with tetraplegia could activate the brachial triceps muscle, while the other two subjects could not. The results have been related to an image of the rim as a clock with "12 o'clock" representing the highest point on the wheel. The solid vertical line divides the rim phase into pull and push phases. The thin horizontal lines designate the points where there was hand contact with the rim. The hatched vertical lines designate the subjects' average point of initiation and termination of contact between the hand and the rim. The filled horizontal bars indicate the EMG activity for each subject. The values to the right of the "rim phase" represent the range of maximal voluntary contraction (MVC) EMG amplitudes for all subjects during wheelchair ambulation in relation to that noted at maximal voluntary contraction (MVC) of the individual muscles. The temporal muscle activation during the recovery phase is also indicated. The individual type of recovery movement in each test situation is indicated as follows: C = "circular" or elliptical movement, SC = semicircular movement, P = "pumping" movement. Asterisks denote a missing value. Abbreviations for muscles: bb = brachial biceps, bt = brachial triceps, ad = anterior deltoid, pd = posterior deltoid, pm = pectoralis major, t = trapezius.

Subjects with tetraplegia



voluntary control of the arm and trunk muscles between subjects with P and T are reflected in both the general muscle activation pattern and the length of the pull and push phases, as well as in their modifications with increasing velocity. This is so, even when comparing the two groups under approximately the same speed conditions, i.e. subjects with P at normal velocity (2.0 m/s) and subjects with T at maximal velocity (2.4 m/s).

The greater volitional control of the trunk and arm muscles allows subjects with P to have longer pull and push phases and to greatly vary the emphasis on these two phases with different velocities. While there is a relative balance in the length of the pull and push phases around the rim position "12 o'clock" under all conditions in subjects with T, subjects with P shorten their pull phase and prolong their push phase under the maximal

velocity and maximal start conditions compared to the "normal" speed.

The pattern noted here in subjects with P is supported by findings in other studies. Ronchi et al. (8) made a case study of the relationship between the pull and push phases in one subject with P who used two different wheelchairs. They studied the velocity spectrum 0.6–2.5 m/s and noted that the pull phase dominated timewise at the lowest speed. With increasing velocity, its relative dominance and absolute time declined at the same time as the push time remained constant. Vanlandewijck et al. (12) observed a corresponding shift in subjects with P when the speed was increased from 1.1 to 2.2 m/s.

This shift is of considerable interest. Its background can only be speculated upon. It is possible that the push phase offers a biomechanical advantage. The pulling movement demands grabbing the rim, whereas the push phase can be executed as a "stroke" against the rim, thus allowing propulsive action at higher velocities. The difference in force-velocity relationship between the brachial biceps and triceps muscles can also be considered. The relative decline in force with increasing contraction velocity is greater in the brachial biceps than in the brachial triceps muscle (5). Thus, there seem to be good reasons for giving the brachial triceps muscle (a propelling muscle during the push phase) a greater role in achieving and maintaining a high velocity.

Also of interest in this context is that a difference in the pull/push phase dependence between subjects with P and T in a sprint-test situation was anticipated by Dallmeijer et al. (3). However, they did not find such a difference and suggested that this was due to the fact that some of the subjects with T did not have reduced brachial triceps muscle function.

Muscle activation

Of the muscles studied, the brachial biceps and triceps, anterior deltoid and pectoralis major muscles could be anticipated to propel the wheelchair forward, whereas the posterior deltoid and trapezius muscles could be expected to play a role, especially during the recovery phase. Our results support this overall distinction, although individual differences were noted. The posterior deltoid and trapezius muscles showed an unexpected and distinct activity during the rim phase, possibly resulting from the function of stabilizing the shoulders.

The general order of activation of, first, the brachial biceps, thereafter the pectoralis major and anterior deltoid, and then the triceps brachial muscle in subjects

with P at the normal velocity during the rim phase is in line with findings in other studies on subjects with P (6, 7, 12) and able-bodied individuals (13).

In the corresponding situation for subjects with T, simultaneous activation of the brachial biceps, pectoralis major and anterior deltoid muscles is observed at the beginning of the pull phase. In subjects with T, this simultaneous activity pattern is sustained at maximal velocity and maximal start. At the same time, the activation of the brachial biceps is prolonged into the push phase.

This is contrary to the situation with subjects with P, in whom the brachial biceps muscle is generally inactive during the push phase at maximal velocity and maximal start, whereas, at the same time, the other propulsive muscles act in a rather concordant manner.

One of the subjects with T could activate the brachial triceps muscle, while the other two subjects could not and were therefore more dependent on the brachial biceps, anterior deltoid and pectoralis major muscles for their propulsion. This difference is reflected in the length of the pull and push phases as well as in the muscle activation pattern when the normal velocity is compared with the maximal velocity and maximal start. The subjects with T without brachial triceps function also showed a lower speed and cycle frequency at the maximal velocity (Table III), compared with the subject with retained brachial triceps function.

The activation pattern of the deltoid anterior muscle is of particular interest. Recent findings indicate considerably higher fibre type I and lower fibre type IIB percentages in this muscle in subjects with T compared to subjects with P and able-bodied persons (11). The search for the explanation of these differences is illuminated by the present finding of a considerably lower contraction velocity spectrum during wheelchair ambulation in subjects with T than in subjects with P. Support is thereby provided for the hypothesis that isometric or low contraction velocities are important factors underlying transformation from fast to slow fibre types (cf. 10, 11).

In both subjects with P and subjects with T, the activation level of all muscles appeared to increase when normal velocity was compared with maximal velocity and maximally accelerated start, as might be expected.

The activation pattern of the posterior deltoid and trapezius muscles at normal speed at the end of the rim phase and during the recovery phase was, for both groups, in agreement with previous reports on subjects with P (7, 12). This activation pattern remained for

subjects with T during maximal velocity and maximal start, whereas a prolonged activity was noted in subjects with P during the push phase in the same situations. It is difficult to explain the reason for this.

The relative concordance in muscle activation observed within the two different groups contrasts with that reported by Harburn & Spaulding (4). The reason for this may be that subjects with P and T in their study had been injured fairly recently (about one-year-old injuries) and might not yet have acquired a more advanced technique. Furthermore, the subjects did not use their own wheelchairs and were studied under conditions where the cycle frequency was fixed. Thus, the measuring conditions did not represent normal conditions. The importance of studying the wheelchair technique under freely chosen conditions has been demonstrated by Woude et al. (17), who observed that the mechanical efficiency was lower at stroke frequencies both below and above those which were freely chosen.

As a final remark in this context, it is reasonable to stress one of the findings in the present study. This concerns the sitting position, as manifested by the fact that the palms of all subjects were aligned with the wheel axle when hanging down in a relaxed position. This suggests that this sitting position may be optimal.

Recovery movements

In the literature, the recovery movements have been categorized into "circular" and "pumping action" movements (1, 9, 14). It is, however, already apparent from the results presented in the studies mentioned above that there is a need for more categories. Our own findings prompted the introduction of a third category, the semicircular type.

It is interesting to note that the circular recovery movement is used by all subjects under normal conditions. This is understandable, as it involves a swinging phase and thereby appears to be a more relaxed form of recovery, whereas both the pumping movement and the semicircular movement, used at maximal velocity and maximal start, are movements distinctly aimed at rapid initiation of a new propulsive action.

Trunk movements

In line with the present results, the trunk movements during normal velocity wheelchair ambulation have been reported to be rather small ($5-10^\circ$) in subjects with P (1, 9, 12). Although small, these movements can play a

part in the positive propulsive force during the recovery phase, as noted by Vanlandewijck et al. (12) in a free-wheeling test situation. In contrast to the normal velocity situation, and in most subjects in the maximal velocity situation, a major trunk movement ($20-30^\circ$) was seen during maximal start in all subjects with P in the present study. This is contrary to what has been noted in a wheelchair ergometer sprint test in which only minor trunk movements ($4-7^\circ$) were observed (3, 9). It is possible that this is due to the difference in measuring conditions. For instance, Veeger et al. (16) have described differences in the range of trunk movements between wheelchair ergometer and free-wheeling conditions. Another plausible explanation is that the differences are due to the fact that the trunk movements during maximal start in a free-wheeling situation are a transient phenomenon during the acceleration phase. It is interesting to note the quick adaptation of the pattern of movement to the gain in speed. Apparently, the strategy for the maximally accelerated start movement is very efficient in generating force in a slow-speed situation. At the same time, it appears to be costly energywise, which explains its transient existence.

It is concluded that there are both similarities and differences in the movement patterns and muscle activation in subjects with P and T under different ambulation conditions. The differences are of such a magnitude that they need to be taken into consideration when teaching wheelchair techniques and developing rehabilitation programmes for different groups of spinal cord injury victims.

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