Electrical activity of muscles of the trunk during walking

R. L. WATERS AND J. M. MORRIS

*Biomechanics Laboratory, University of California, San Francisco and Berkeley, and
Department of Orthopaedic Surgery, University of California
School of Medicine, San Francisco*

INTRODUCTION

In contrast to the muscles of the lower limbs, little attention has been paid to the muscles of the trunk during ambulation. This neglect is partially understandable since, as compared with limb muscles, trunk muscles are difficult to palpate individually or observe separately during contraction. Moreover, movement of the trunk is brought about by intricately patterned contributions of many different muscles, so that the effect of a single muscle is difficult to demonstrate.

Electromyography has proved an effective means of studying the function of muscles of the trunk. Morris, Benner & Lucas (1962) placed electrodes in specific muscles of the back to demonstrate electro-myographically the contributions of muscle groups in flexion–extension, rotation and other movements of the trunk. Similar experiments have been made on abdominal muscles with the subjects performing isolated motions in the supine and standing positions (Walters & Partridge, 1957; Floyd & Silver, 1950).

Joseph & McColl (1961), using surface electrodes to record the activity of the posterior vertebral muscles, found that, in the standing-at-ease position, the activity of these muscles varied at different levels. The level of each specific muscle studied by us is given in Table 1. It is recognized that there may be minor variations in activity at other vertebral levels, but our investigation of back muscles was not concerned with the vertebral level but with which muscles (and muscle groups) are active during standing and during walking at two speeds. Our intention was to interpret such activity in terms of phases of the walking cycle. We believed that a pattern might emerge. In contrast to Joseph, we chose to use electrodes placed within the muscle rather than surface electrodes, which, for our purposes, were believed to be too 'noisy' for recording the walking subject. We chose this method of study because we wished to expand it to obtain data on subjects walking with certain spinal supports (a chairback brace and a lumbosacral corset) in order to test their effect on muscle activity. This second study (Waters & Morris, 1970) has been reported in the literature.

Walking requires an upset of the delicate balance of the trunk, which is maintained by minimum muscle activity during standing at rest. During ambulation the pelvis undergoes significant translational and rotary motion in the sagittal, coronal and transverse planes. Therefore, the requirements for balancing the trunk by action of the trunk muscles are much more complex than during standing.

Table 1. *Locations of embedded wire electrodes*

Muscle	Electrode	Location
Iliocostalis thoracis	1	Over 7th rib, ¼ distance from angle of rib to spine
	2	Over 6th rib, ¼ distance from angle of rib to spine
Longissimus thoracis	1	Over 9th rib, ½ distance from angle of rib to spine
	2	Over 10th rib, ½ distance from angle of rib to spine
Iliocostalis lumborum	1	Over 11th rib, ¼ distance from angle of rib to spine
	2	Over 12th rib, ¼ distance from angle of rib to spine
Multifidus	1	2 cm below line joining iliac crests, 1 cm lateral to 5th lumbar spinous process
	2	3 cm below line joining iliac crests, 1 cm lateral to 5th lumbar spinous process
Rotatores	1	1 cm lateral to 10th thoracic spinous process
	2	2 cm below electrode 1
Quadratus lumborum	1	1 cm above and 1 cm lateral to posterior superior iliac spine
	2	2 cm above and 2 cm lateral to posterior superior iliac spine
Rectus abdominis	1	1 cm lateral to linea alba (in centre of muscle segment)
	2	2 cm superior to umbilicus
Obliquus externus abdominis	1, 2	2 cm apart along the lower costal margin between the anterior axillary and the midclavicular lines
Obliquus internus abdominis	1	3 cm above and perpendicular to inguinal ligaments
	2	4 cm medial to anterior superior iliac spine

The purpose of the present study was to examine the electrical activity of specific muscle groups of the back and abdomen in an attempt to define their functions during ambulation.

MATERIALS AND METHODS

Ten normal young adult male and female volunteers were recruited from the student population of San Francisco State College. The only criteria for exclusion were a history of back disease, or pathological conditions of the trunk and extremities as determined by physical examination (see Table 2).

All recordings were made from the right side of the body; it was assumed that the electrical activity would be essentially the same on both sides. The intrinsic muscles of the back and three of the four major abdominal muscles were studied. Two recording electrodes (fine, stainless-steel wires with the insulation removed at the tips) were placed 2 cm apart in each muscle. Placement was made by threading the electrode through a 25-gauge hypodermic needle; after insertion the needle was removed. The electrode was padded at the level of the skin to prevent irritation or pull. No discomfort was reported by the subjects during walking with electrodes in place.

Electrode placement in the iliocostalis thoracis, longissimus thoracis, iliocostalis lumborum, multifidus and rotatores was the same as that described by Morris *et al.* (1962). Electrodes were inserted in the quadratus lumborum by piercing the posterior part of the thoracolumbar fascia above and lateral to the posterior superior iliac spine. Insertion of the electrodes into the rectus abdominis, obliquus externus ab-

Table 2. *Sex, weight and height of subjects and step*
frequency at 4·39 and 5·29 km/hour

Subject	Sex	Weight (kg)	Height (cm)	Step frequency 4·39 km/h (steps/min)	Step frequency 5·29 km/h (steps/min)
1	M	64	179	101	110
2	M	62	178	104	111
3	M	59	182	101	112
4	M	72	185	100	107
5	F	46	165	108	124
6	F	51	170	103	123
7	M	74	182	97	109
8	M	62	175	102	112
9	F	45	166	110	120
10	F	40	155	115	125

dominis and obliquus internus abdominis was carried out as described by Waters &
Morris (1970) (Table 1). The transversus abdominis was not studied because it has
been found to be extremely difficult to avoid puncture of the peritoneum when
placing electrodes. All electrode positions had first been determined by studies on
cadavers. Since all the muscles investigated were large and relatively discrete, it was
felt that positioning of the electrodes within the individual muscles was properly
achieved in all cases.

Subjects were conditioned to treadmill walking prior to testing. Each test consisted
of three parts. With the electrodes in place, the subject stood at rest, then walked on a
level treadmill at 4·39 km/hour (previously determined to be a 'comfortable' walking
speed by Ralston, 1958), and 5·29 km/hour (a fast walk). To prevent a bias that might
result from a consistent order of tests, arbitrary sequences were made with the sub-
jects standing and walking at both speeds.

Signals from the electrodes were amplified by a six-channel electromyograph
designed and constructed in the Biomechanics Laboratory. Simultaneously with the
electromyogram, heel strike was recorded by means of electrical switches attached to
the subject's shoes. Proper amplification for each muscle studied was determined
initially by observation of the oscilloscope records and was then kept constant
throughout the experiment. Permanent records were obtained with a Honeywell
Visicorder. Representative electromyograms were selected to provide an adequate
demonstration of the phasic activity found during walking.

RESULTS

Activity of the trunk muscles during standing at rest

Subjects were instructed to stand relaxed, with their weight evenly distributed on
both legs, with their arms at their sides and with their feet parallel, 3–4 in. apart.

In the back muscles, a low level of intermittent electrical activity occurred in three
subjects in the iliocostalis thoracis, in five subjects in the longissimus thoracis, in
eight subjects in the iliocostalis lumborum, in eight subjects in the multifidus, in all
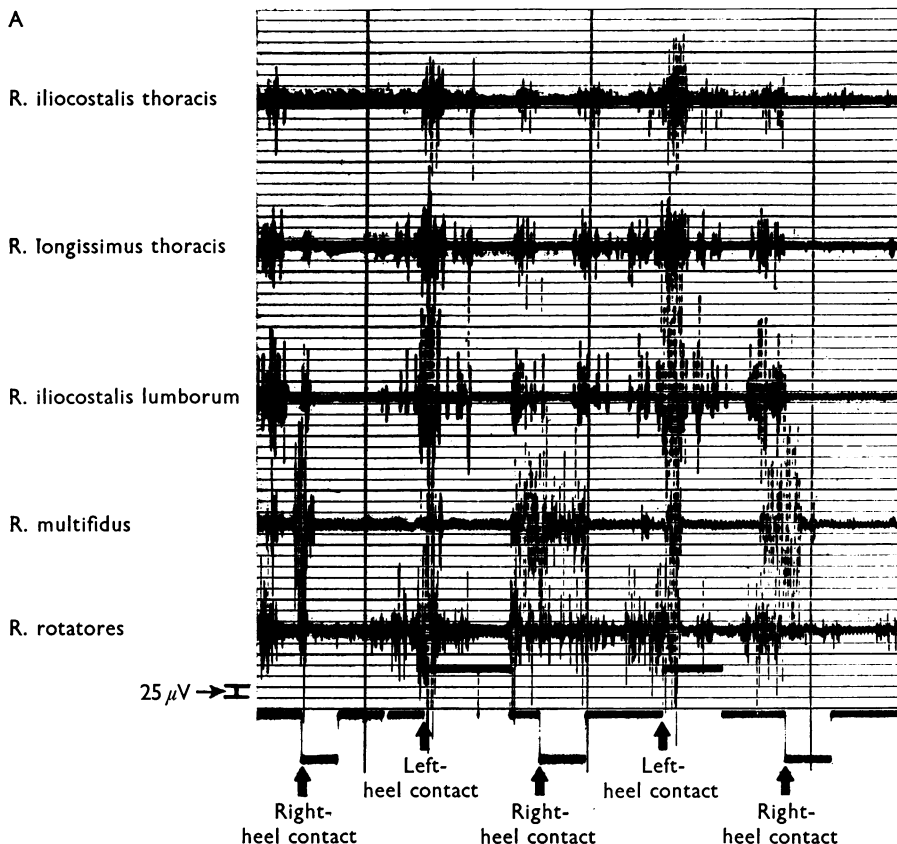
A

R. iliocostalis thoracis

R. longissimus thoracis

R. iliocostalis lumborum

R. multifidus

R. rotatores

25 μV →

Left-heel contact   Left-heel contact

Right-heel contact   Right-heel contact   Right-heel contact

Fig. 1. Electromyograms of two subjects walking at 4·39 and 5·29 km/hour, demonstrating the discrete periods of electrical activity of trunk muscles in a consistent relation to heel strike.

subjects in the rotatores, and in three subjects in the quadratus lumborum. However, sporadic electrical activity occurred simultaneously in all back muscles with minor postural changes.

No activity was observed in the rectus abdominis muscle at any time. In the obliquus internus, six of ten subjects exhibited a low level of electrical activity; in the obliquus externus, three of ten subjects demonstrated slight activity. Occasional short bursts of increased activity occurred simultaneously in all subjects in both the latter muscles as minor postural changes occurred.

Activity of the trunk muscles during walking

Striking periodic electrical activity of the trunk muscles was seen in all subjects during ambulation at both walking speeds; it was repetitive in each walking cycle (Fig. 1). Moreover, the electromyogram of a given muscle in any two subjects was similar in duration and in relationship to heel strike.

To compare the electrical activity of the same muscles among subjects walking at the same treadmill speeds but with different step frequencies, the average time inter-
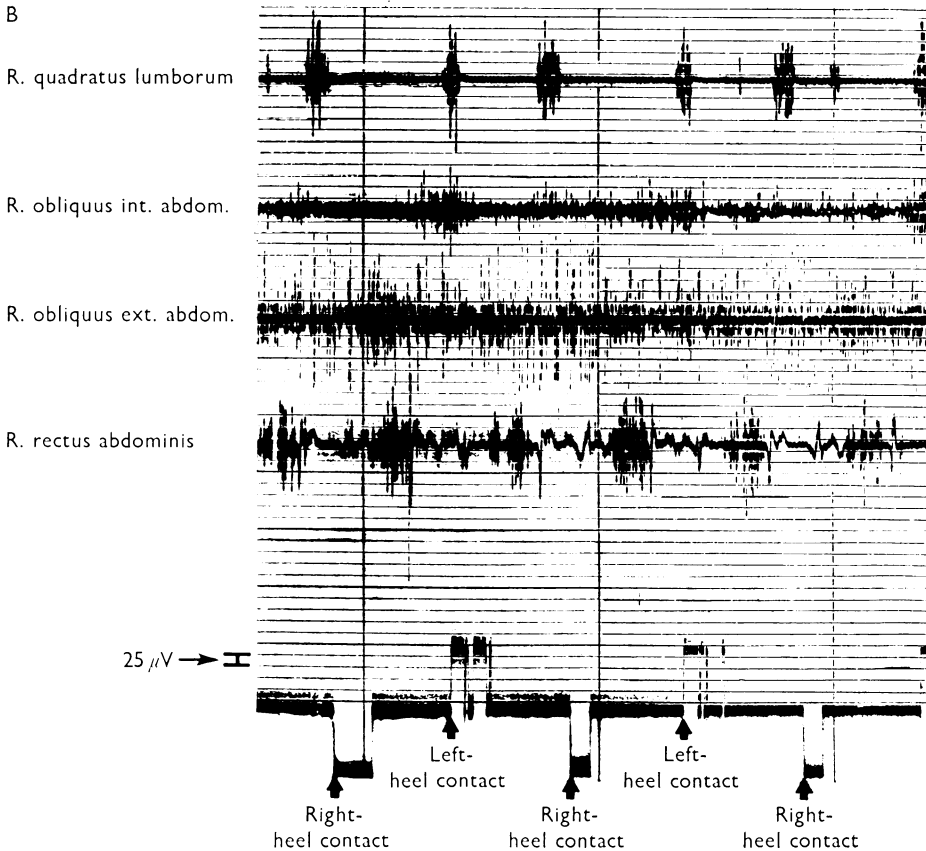
B

R. quadratus lumborum

R. obliquus int. abdom.

R. obliquus ext. abdom.

R. rectus abdominis

25 μV

Left-
heel contact

Left-
heel contact

Right-
heel contact

Right-
heel contact

Right-
heel contact

Fig. 1*B*. For legend see opposite.

vals between onset of each period of electrical activity and both heel strikes and cessation of electrical activity and both heel strikes were determined for each muscle over ten successive walking cycles. These averages were then expressed as percentages of the walking cycle to allow for differences in duration of the cycle. The results are graphically expressed in Fig. 2.

Ambulation at 4·39 km/hour.

Right erector spinae group. Electrical activity began before and stopped after left heel strike in all subjects at approximately the same time in the three portions of the muscle tested (Fig. 2). Electrical activity at right heel strike occurred variably and was of substantially less magnitude than at left heel strike. When present it tended to occur in two small bursts before and after heel strike. It was not always present, occurring in five subjects in the iliocostalis thoracis and in seven subjects in the longissimus thoracis; it occurred in all subjects in the iliocostalis lumborum.

The standard deviations of onset and of cessation of activity at left heel strike in the three portions of the erector spinae did not exceed 4 % of the walking cycle in an
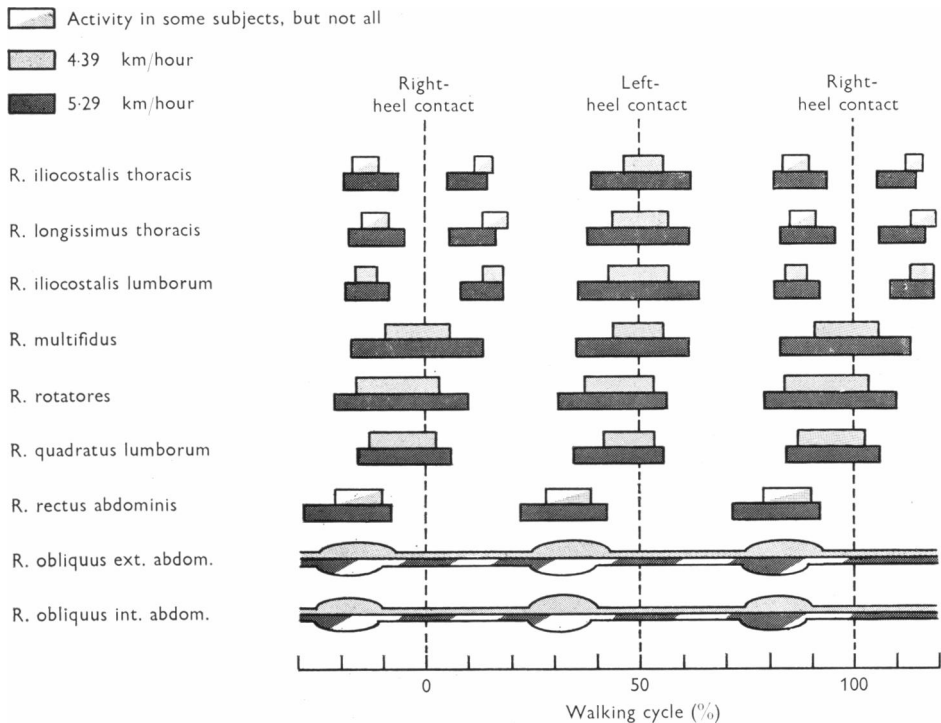
Fig. 2. The average duration of electrical activity of trunk muscles in ten subjects walking at 4·39 and 5·29 km/hour. This figure represents a composite picture of the period of time during the walking cycle that activity of the specific muscles was observed in our subjects. Since this is a composite, any one set of electromyograms from a single individual will not exactly 'fit' for every specific muscle studied.

individual, or 7 % in all the subjects together. Activity at right heel strike was too irregular to determine the variance among subjects.

Right multifidus and rotatores muscles. During walking, consistent electrical activity was recorded at about the time of right and left heel strike. In the multifidus, the duration of activity in the group of subjects at right heel strike exceeded that at left heel strike by 5 % of the walking cycle. Similarly, in the rotatores activity at right heel strike was slightly greater, 3 %, than at left heel strike.

The standard deviations of the time of onset and of cessation of electrical activity of the multifidus and rotatores and of heel strike were small and did not exceed 5 % of the walking cycle for each muscle during ten successive steps in the same subject, or 8 % of the walking cycle in each muscle in the group of subjects.

Right quadratus lumborum muscle. Electrical activity occurred in the quadratus lumborum in all subjects at about the same time as activity in the multifidus and rotatores. Activity at right heel strike lasted slightly longer. The standard deviations of onset and cessation did not exceed 10 % of the walking cycle in an individual or 15 % in the group.

Right abdominal muscles. In the rectus abdominis, five of ten subjects displayed

electrical activity. When present it occurred identically before right and left heel strike. In an individual, the electrical activity varied by less than 5 % of the walking cycle, and in the group of subjects it varied less than 9 %.

In the obliquus internus abdominis and obliquus externus abdominis muscles, continuous electrical activity was recorded throughout the walking cycle. There was often an increase in amplitude of electrical activity coincidental with activity of the rectus.

Walking at 5·29 km/hour

At the fast walking speed, similar phasic electrical activity was recorded. The results are summarized in Fig. 2; only major differences from the electrical activity occurring at 4·39 km/hour will be mentioned. The amplitude and duration of electrical activity were greater and the bursts of electrical activity more discrete. In contrast to the results at 4·39 km/hour phasic electrical activity occurred in the rectus abdominis and, at right heel strike, in the erector spinae group in all subjects. In the obliquus muscles, five subjects showed prominent phasic increases of electrical activity coincidental with the activity of the rectus, superimposed on a background of continuous activity; two subjects displayed phasic activity only; and three subjects displayed continuous activity only.

DISCUSSION

The action of trunk muscles may be anticipated by a knowledge of their attachments. Electromyographic studies of back muscles of subjects performing movements from a standing position have confirmed functional expectations (Morris *et al.* 1962; Morris *et al.*, 1961).

It has been known since the earliest studies of electrical activity of muscle that, except for such muscles as those of respiration, the skeletal musculature of the body is electrically silent during rest in the horizontal position, whether supine or prone. Some activity of the back muscles occurs during standing. Asmussen (1960) thought that this was because the centre of gravity of the trunk lay in front of the supporting vertebral elements. Dempster (1955) determined that the centre of gravity of the thorax lay adjacent to the T9–T10 disc interspace and anterior to the anterior longitudinal ligament. The back muscle activity observed in this experiment tends to support Asmussen's view and assumption that extensor muscle activity is required to prevent forwards flexion of the trunk.

During walking, the trunk must balance on the pelvis, which moves along vertical and lateral as well as progressional axes. Along the vertical axis the trunk reaches maximum downwards displacement when its weight is centred approximately between both feet in double support phase; maximum upwards displacement occurs when it is centred over the supporting foot during single stance. The force exerted by the ground on subjects' feet during walking has been measured in force plate studies (*Fundamental Studies of Human Locomotion*, 1947; Cavagna & Margaria 1966). Shortly after heel strike an upwards force, which exceeds body weight, is exerted on the foot by the ground. This force is transmitted by the leg to the pelvis and trunk and accounts for the up-and-down displacement of the trunk. This upwards displacement would tend to flex the trunk forwards because of the relatively

anterior location of the centre of gravity of the body. However, it seems probable that the extensor muscle activity of the erector spinae, the multifidus and the rotatores, observed to occur at heel strike in this experiment, acts to oppose the tendency of the trunk to flex.

Bending forwards from a standing position requires no activity on the part of the rectus abdominis (Floyd & Silver, 1950). Walking is associated with phasic electrical activity in the rectus, the major portion of which is observed to occur before significant activity on the back muscles. The rectus appears to exert a stabilizing flexion force.

During walking the trunk moves laterally to balance itself over the supporting foot (*Fundamental Studies of Human Locomotion*, 1947; Murray, Drought & Kory, 1964). Activity of the erector spinae, multifidus, rotatores and quadratus lumborum muscles provides stabilization of the trunk in the lateral plane.

During walking the trunk also rotates about a vertical axis. During walking at higher speeds, at right heel strike the pelvis and the lower vertebrae rotate clockwise and the shoulder girdle and upper vertebrae rotate counterclockwise (Gregersen & Lucas, 1967; Chapman & Kurokawa, 1968). The significantly greater amount of activity of the erector spinae muscle group at left heel strike may exert a force which contributes to these rotations.

During walking at 4·39 km/hour, continuous activity of the obliquus internus and obliquus externus muscles was observed by us. At this faster rate accelerations of the trunk are of course greater. This would account for the increased electrical activity of the trunk muscles observed at the faster walking speed and reflects the increased need for muscle forces to balance the trunk.

SUMMARY

Motion of the pelvis during walking requires an intricate pattern of muscle forces to balance the superimposed trunk. The electrical activity of selected trunk muscles was determined in ten subjects during standing and during walking at a comfortable and at a fast pace. The periods of electrical activity are related to the requirements for trunk support.

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