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ON THE PRODUCTION OF NEUROMUSCULAR PATTERNS BY RELEASE OF SPINAL INTEGRATIONS AFTER DECEREBRATION.*

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- I.—INTRODUCTION.
- II.—THE NEUROMUSCULAR MECHANISM.
- III.—A NEUROMUSCULAR ANALYSIS OF THE EXPERIMENTAL AND CLINICAL
EVIDENCE FOR DECEREBRATE RIGIDITY AND THE FLEXION REFLEX.
 - A. The Experimental Evidence.
 - B. The Clinical Evidence for Decerebrate Rigidity.
 - C. The Clinical Evidence for the Flexion Reflex.
 - D. Summary.
- IV.—CASE REPORTS.
- V.—THE FLEXION REFLEX POSITION OF THE ARM.
- VI.—THE RELATION OF POSTURE PATTERNS TO TONE.
- VII.—THE KINETIC AND STATIC TYPES.
- VIII.—SUMMARY AND CONCLUSIONS.

I.—INTRODUCTION.

THANKS to the efforts of S. A. K. Wilson, we now have a clinical application of that part of the experimental work of Sherrington which demonstrated the existence, after removal of the more anterior parts of the central nervous system, of the condition known as decerebrate rigidity. This clinical and pathological study promises to clear up many of the obscure problems, not only of defects of posture, but of the physiology of the nervous system in general. It

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VOL. III.—NO. 11. 15

is our desire to assist in this by analyzing, from a new angle, a series of cases showing decerebrate posture.

One of us¹ in November, 1921, presented a preliminary general outline of this new approach to the subject of motility and posture. In this paper decerebrate postures will be considered from that point of view.

II.—THE NEUROMUSCULAR MECHANISM.

The essential point of the neuromuscular approach to the subject of motility and posture lies in two assumptions. One is that a description of groups of movements in terms indicating merely the activity of muscles in changing the position of various parts of the body in a geometrical sense has, on careful analysis, no definite relationship to any integration of movements by the spinal cord or higher centres of the nervous system. The other assumption is that movements, grouped or isolated, must be considered as activated by the nervous system in patterns primarily dependent upon the primitive and anatomical grouping of muscles, and not upon their function only. The peripheral motor neurones and their end-organs, the muscles, have group relations indicating integration by the spinal cord. This implies that the anatomical grouping of muscles, the common nerve-supply of certain groups of them, their common origin on certain aspects of the body, must form bases for the interpretation of group movements. The simplest example of this is the division of the musculature of the back, neck, and abdominal wall into dorsal and ventrolateral groups. The application of this information to physiology reveals immediately that the dorsal group causes extension while the ventrolateral group causes flexion. The lateral and rotatory movements produced by these groups of muscles are due to over-activity of the right or left halves of either the dorsal or ventral groups or both.

23 — In the more distant portions of the extremities the muscles also develop in large 'premuscle masses' from the ventral and dorsal aspects.² These masses give rise to groups of muscles whose nerve-supply are respectively dorsal and ventral. For example, of the branches of the brachial plexus going to the arm, forearm, and hand, the circumflex and musculospiral are dorsal, and innervate muscles derived from the dorsal premuscle mass, while the musculocutaneous, median, and ulnar are ventral, and supply muscles derived from the ventral premuscle mass. However, an examination of the functions of muscles does not always reveal a correspondence between actual function and that expected. In other words, muscles developing on the dorsal aspect of the limb have not always dorsal functions, such as extension, and vice versa. The best examples of this are as

follows: The muscles ilio-psoas, pectineus, sartorius, on the anterior aspect of the thigh, since they are dorsal in origin (part of the so-called femoral group), would, by analogy with the axial muscles, be expected to have an extensor function, whereas, in reality, their function is flexor. In the hand the interossei extend the terminal phalanges, though, with the exception of the abductor digiti quinti, all the other muscles supplied by the ulnar nerve and of the same group have a flexor function. Since the actual anatomical facts form the basis of the entire matter, these must be presented at once. In *Tables I, II, and III* the muscles of the body, except those supplied by cranial nerves, will be found arranged in dorsal and ventral groups. In *Table IV* the spinal motor nerves will be found so arranged. This last tabulation has been taken from Patterson's article in Cunningham's *Text-book of Anatomy*.³

Table I.—DIVISION OF THE MUSCLES OF THE UPPER EXTREMITY INTO VENTRAL AND DORSAL GROUPS.

MUSCLE	VENTRAL	DORSAL
1.—Levator scapulæ		×
2.—Serratus anterior		×
3.—Rhomboides major		×
4.—Rhomboides minor		×
5.—Supraspinatus		×
6.—Infraspinatus		×
7.—Teres minor		×
8.—Deltoid		×
9.—Subscapularis		×
10.—Teres major		×
11.—Latissimus dorsi		×
12.—Subclavius	×	
13.—Pectoralis major	×	
14.—Pectoralis minor	×	
15.—Biceps brachii	×	
16.—Brachialis*	×	
17.—Coracobrachialis	×	
18.—Brachioradialis		×
19.—Extensor carpi radialis longus		×
20.—Extensor carpi radialis brevis		×
21.—Supinator		×
22.—Extensor pollicis longus		×
23.—Extensor indicis proprius		×
24.—Abductor pollicis longus		×
25.—Extensor pollicis brevis		×
26.—Extensor communis digitorum		×
27.—Extensor carpi ulnaris		×
28.—Extensor minimi digiti quinti		×
29.—Anconeus		×
30.—Triceps		×

*Supplied by both dorsal and ventral nerves.

Table I.—DIVISION OF THE MUSCLES OF THE UPPER EXTREMITY INTO VENTRAL AND DORSAL GROUPS—*continued*.

MUSCLE	VENTRAL	DORSAL
31.—Pronator teres - - - -	×	
32.—Flexor carpi radialis - - -	×	
33.—Palmaris longus - - - -	×	
34.—Flexor digitorum sublimis -	×	
35.—Flexor digitorum profundus	×	
36.—Flexor pollicis longus - -	×	
37.—Pronator quadratus - - -	×	
38.—Lumbricalis 1 - - - - -	×	
39.—Lumbricalis 2 - - - - -	×	
40.—Lumbricalis 3 - - - - -	×	
41.—Lumbricalis 4 - - - - -	×	
42.—Abductor pollicis brevis -	×	
43.—Opponens pollicis - - - -	×	
44.—Flexor pollicis brevis (lateral head)	×	
45.—Flexor pollicis brevis (medial head)	×	
46.—Flexor carpi ulnaris - - -	×	
47.—Adductor pollicis obliquus -	×	
48.—Adductor pollicis transversus	×	
49.—Interosseus volaris 1 - - -	×	
50.—Interosseus volaris 2 - - -	×	
51.—Interosseus volaris 3 - - -	×	
52.—Interosseus dorsalis 1 - - -	×	
53.—Interosseus dorsalis 2 - - -	×	
54.—Interosseus dorsalis 3 - - -	×	
55.—Interosseus dorsalis 4 - - -	×	
56.—Opponens digiti quinti - - -	×	
57.—Flexor digiti quinti brevis -	×	
58.—Abductor digiti quinti - - -	×	

Table II.—DIVISION OF THE MUSCLES OF THE LOWER EXTREMITY INTO VENTRAL AND DORSAL GROUPS.

MUSCLE	VENTRAL	DORSAL
1.—Iliacus - - - - -		×
2.—Psoas major - - - - -		×
3.—Psoas minor - - - - -		×
4.—Pectineus* - - - - -		×
5.—Sartorius - - - - -		×
6.—Rectus femoris - - - - -		×
7.—Vastus lateralis - - - - -		×
8.—Vastus medialis - - - - -		×
9.—Vastus intermedius - - - -		×

*Supplied by both dorsal and ventral nerves.

Table II.—DIVISION OF THE MUSCLES OF THE LOWER EXTREMITY INTO VENTRAL AND DORSAL GROUPS—*continued*.

MUSCLE	VENTRAL	DORSAL
10.—Tensor fasciæ latæ - - - -		×
11.—Gluteus minimus - - - -		×
12.—Gluteus medius - - - -		×
13.—Piriformis - - - -		×
14.—Gluteus maximus - - - -		×
15.—Biceps femoris (short head) - - - -		×
16.—Biceps femoris (long head) - - - -	×	
17.—Semitendinosus - - - -	×	
18.—Semimembranosus - - - -	×	
19.—Adductor magnus - - - -	×	
20.—Obturator externus - - - -	×	
21.—Adductor longus - - - -	×	
22.—Adductor brevis - - - -	×	
23.—Gracilis - - - -	×	
24.—Obturator internus - - - -	×	
25.—Superior gemellus - - - -	×	
26.—Inferior gemellus - - - -	×	
27.—Quadratus femoris - - - -	×	
28.—Tibialis anterior - - - -		×
29.—Extensor hallucis longus - - - -		×
30.—Extensor digitorum longus - - - -		×
31.—Peroneus tertius - - - -		×
32.—Peroneus longus - - - -		×
33.—Peroneus brevis - - - -		×
34.—Extensor digitorum brevis - - - -		×
35.—Gastrocnemius - - - -	×	
36.—Soleus - - - -	×	
37.—Plantaris - - - -	×	
38.—Popliteus - - - -	×	
39.—Tibialis posterior - - - -	×	
40.—Flexor digitorum longus - - - -	×	
41.—Flexor hallucis longus - - - -	×	
42.—Quadratus plantæ - - - -	×	
43.—Abductor digiti quinti - - - -	×	
44.—Flexor digiti quinti brevis - - - -	×	
45.—Opponens digiti quinti - - - -	×	
46.—Interosseus plantaris 1 - - - -	×	
47.—Interosseus plantaris 2 - - - -	×	
48.—Interosseus plantaris 3 - - - -	×	
49.—Interosseus dorsalis 1 - - - -	×	
50.—Interosseus dorsalis 2 - - - -	×	
51.—Interosseus dorsalis 3 - - - -	×	
52.—Interosseus dorsalis 4 - - - -	×	
53.—Adductor hallucis - - - -	×	
54.—Lumbricalis 1 - - - -	×	
55.—Lumbricalis 2 - - - -	×	
56.—Lumbricalis 3 - - - -	×	
57.—Lumbricalis 4 - - - -	×	
58.—Abductor hallucis - - - -	×	
59.—Flexor digitorum brevis - - - -	×	
60.—Flexor hallucis brevis - - - -	×	

Table III.—DIVISION OF THE MUSCLES OF THE AXIS INTO VENTRAL AND DORSAL GROUPS.

MUSCLE	VENTRAL	DORSAL
Muscles of the Back.		
Serratus posterior superior - - -		x
Serratus posterior inferior - - -		x
Splenius - - -		x
Sacrospinalis - - -		x
Iliocostalis - - -		x
Longissimus - - -		x
Spinalis dorsi - - -		x
Semispinalis - - -		x
Multifidus - - -		x
Obliquus capitis inferior - - -		x
Obliquus capitis superior - - -		x
Rectus capitis posterior major - - -		x
Rectus capitis posterior minor - - -		x
Rotatores - - -		x
Interspinales - - -		x
Intertransversarii - - -	x	
Trapezius - - -		x
Muscles of the Neck.		
Scalenus anterior - - -	x	
Scalenus medius - - -	x	
Scalenus posterior - - -	x	
Longus capitis - - -	x	
Rectus capitis anterior - - -	x	
Longus colli - - -	x	
Rectus capitis lateralis - - -	x	
Sterno-cleido-mastoid - - -	x	
Muscles of the Thorax.		
Intercostales - - -	x	
Levatores costarum - - -	x	
Subcostales - - -	x	
Transversus thoracis - - -	x	
Muscles of the Abdominal Wall.		
Obliquus externus abdominis - - -	x	
Obliquus internus abdominis - - -	x	
Cremaster - - -	x	
Transversus abdominis - - -	x	
Pyramidalis abdominis - - -	x	
Rectus abdominis - - -	x	
Quadratus lumborum - - -	x	
Muscles of the Perineum.		
Sphincter ani externus - - -	x	
Corrugator cutis ani - - -	x	
Transversus perinei superficialis - - -	x	
Bulbocavernosus - - -	x	
Ischiocavernosus - - -	x	
Sphincter urethræ membranaceæ - - -	x	
Transversus perinei profundus - - -	x	
Muscles of the Pelvis.		
Levator ani - - -	x	
Coccygeus - - -	x	

Table IV.—DIVISION OF THE NERVES OF THE EXTREMITIES INTO DORSAL AND VENTRAL GROUPS.

ORIGIN	NERVES	
<i>Upper Extremity.</i>		
Brachial Plexus.	Dorsal trunks (posterior cord)	{ Dorsal scapular Long thoracic Suprascapular Subscapular (2) Thoraco-dorsal Axillary Radial
	Ventral trunks (lateral and medial cords)	{ Nerve to subclavius Anterior thoracic (2) Musculocutaneous Median Ulnar
<i>Lower Extremity.</i>		
Lumbo-sacral Plexus.	Dorsal trunks	{ Superior gluteal Inferior gluteal Nerve to piriformis Femoral Peroneal
	Ventral trunks	{ Obturator Nerve to obturator internus and superior gemellus Nerve to quadratus femoris and inferior gemellus Tibial

This division of the nerves and, as naturally would follow, of the muscles of the body, is also to be found in part in Braus,⁴ Quain's *Anatomy*,⁵ and Lewandowsky.⁶ Indeed, the whole general notion of such a division was recognized to a certain extent by Thomas Huxley⁷ in 1871, in his description of the surfaces of the limbs and their axial borders. Since the functions of these muscles, particularly those of the limbs, are familiar to all, they have not been included in the tables. The difference between an expected function in terms of the dorsal or ventral origin of a given muscle and its real function has been emphasized briefly by citing the femoral group and the dorsal interossei. When this same critical examination of the correspondence between function and origin of muscles is applied to the hamstrings, for example, it is found that whereas they flex at the knee, they also extend at the hip—a curious combination. When the movements at the ankle are considered, it is found that the gastrocnemius and soleus group, though posteriorly placed in the leg, and though developing from what is really its ventral aspect,

have a dorsal function, extension. They are innervated by a ventral nerve which also innervates the flexors of the toes and the intrinsic flexors of the foot. The confusion which has resulted from this alone is tremendous. The attempts to reconcile function on one hand, with anatomy, embryology, and nerve-supply on the other, have led to insurmountable difficulties so far as any satisfactory solution is concerned. However, when in addition to actual movements of muscles, we consider their embryological grouping and their nerve supply, we find that all of these difficulties disappear.

In order to keep in mind this division of muscles, it is proposed that the words 'ventrad' and 'dorsad' be added when necessary to our present terminology to indicate the control and origin of muscle movements such as extension, flexion, abduction, etc.; the suffix 'ad' instead of 'al' is thus used to indicate that primitively these muscles produced movements to and from the ventral surfaces of the body. To be sure, all movements are not primarily such, but a group of movements such as flexion, internal rotation, adduction, and inversion obviously have the same general effect, while the movements of extension, abduction, external rotation, and eversion have the opposite effect.

In another paper⁸ emphasis is laid upon the fact that the movements of the leg in normal gait can be resolved into four phases: (1) A ventral fin-like movement at the hip; (2) A dorsal fin-like movement at the hip; (3) The flexion reflex element; (4) The support element.

The first two of these represent movements of the extremities of a vertebrate with but singly-hinged appendages, namely fins. When, in the course of vertebrate evolution, fish developed into land animals, amphibia, and acquired three-hinged appendages, more complex movements were necessary. The three-hinged appendage had not only to be locked in extension to counteract gravity, but had also to be withdrawn from the ground. Land animals therefore developed a more complicated integration of the nervous system to control this. These two latter sets of movements, which are corresponding opposites, include the two last elements of gait, those of flexion and support, and it is these which are made manifest in an uncontrolled fashion by the process of decerebration, either experimentally in animals or by disease in man.

The position of antigravity posture as defined by Sherrington^{9, 10} is spoken of as 'extension', while the flexion reflex element is spoken of as 'flexion'. The impression given, therefore, is that these two sets of movements are physiologically homogeneous, and the implication is that the nervous system bears a similar relation in controlling them. However, in the following it will be shown that both the

extension and flexion alluded to consist of an alternation of ventral and dorsal movements, not a simple and homogeneous reaction. These reflexes of posture and progression are, of course, guided by integrations of the spinal cord. Their make-up is obviously more complex than one which would simply guide the movements of a large ventral or dorsal group of muscles in a concerted fashion. The postural reaction of the trunk of the body in opisthotonus illustrates by way of contrast a simple over-activity of the dorsal group in relation to the ventral group.

III.—A NEUROMUSCULAR ANALYSIS OF THE EXPERIMENTAL AND CLINICAL EVIDENCE FOR DECEREBRATE RIGIDITY AND FLEXION REFLEX.

A. The Experimental Evidence.—In a paper entitled “The Reflex Mechanism of the Step”, Sherrington⁹ has given the actual

FIG. 1.—Figure illustrating the muscles actually observed by experimental analysis to be engaged in contracting in the flexion-phase (A) and in the extension-phase (B) of the reflex step of the cat.

- A. Tibialis anticus.
 B. Biceps femoris posterior.
 E. Extensor brevis digitorum.
 F. Tensor fasciæ femoris brevis.
 G. Gracilis.
 I. Psoas.
 L. Extensor longus digitorum.
 M. Gluteus minimus.
 P. Peroneus longus.
 R. Rectus femoris.
 S. Sartorius lateralis.
 S'. Sartorius medialis.
 T. Semitendinosus.

- B. Quadratus femoris.
 1. Crureus.
 2. Vasti.
 3. Adductor minor.
 4. Adductor major (a part).
 5. Semimembranosus.
 6. Biceps femoris posterior.
 7. Gastrocnemius.
 8. Soleus.
 9. Flexor longus digitorum.

(By permission of 'Brain'.)

Table V.—THE ABOVE MUSCLES ARRANGED IN VENTRAL AND DORSAL GROUPS.

Note.—In both tables *Group I* includes muscles acting at the hip, *Group II* those acting at the knee, *Group III* those acting at the ankle. *Fl.* = Flexion; *Ext.* = Extension; *Ad.* = Adduction.

GROUP	A		B	
	VENTRAL	DORSAL	VENTRAL	DORSAL
I.		I. Psoas M. Gluteus minimus R. Rectus femoris F. Tensor fasciæ femoris brevis S. Sartorius lateralis S. Sartorius medialis	0. Quadratus femoris 3. Adductor minor 4. Adductor major (a part) 5. Semimembranosus 6. Biceps femoris. <i>posterior</i>	
II.	B. Biceps femoris posterior G. Gracilis T. Semitendinosus			1. Crureus 2. Vasti
III.		A. Tibialis anticus L. Extensor longus digitorum P. Peroneus longus E. Extensor digitorum brevis	7. Gastrocnemius 8. Soleus 9. Flexor longus digitorum	

THE CORRESPONDING MUSCLES IN MAN.*

I	Pectineus (Fl. & Ad. hip)	Iliopsoas (Fl. hip) Tensor fasciæ femoris (Fl. hip) Sartorius (Fl. hip) <i>Ad</i> Pectineus (Fl. hip) <i>Ad</i>	Adductors (Ad. hip) Semimembranosus (Ext. hip) Semitendinosus (Ext. hip) Biceps femoris (Ext. hip)	
II	Gracilis (Fl. & Ad. knee) Semitendinosus (Fl. knee) Semimembranosus (Fl. knee) Biceps femoris (Fl. knee)			Quadriceps femoris (Ext. knee)
III		Tibialis anticus (Fl. ankle) Extensor digitorum longus (Fl. ankle) Extensor longus hallucis (Fl. ankle)	Gastrocnemius (Ext. ankle) Soleus (Ext. ankle) Tibialis posticus (Ext. ankle)	

*This does not account for all the muscles of the lower extremities, since observation or testing of all of them has not been possible.

muscles involved in the extension or antigravity phase of reflex stepping and in the flexion phase in the cat. *Fig. 1* represents the results⁹; following this is a table (*Table V*) showing the division of muscles into dorsal and ventral groups, and below this, for convenience and future use, the corresponding muscles in man.

From this it is readily seen that there is a definite alternation of control at the three great joints, the hip, knee, and ankle.

Furthermore, in speaking of the muscles of the axis, Sherrington⁹ states that “when all of the brain in front of a transection between

anterior and posterior colliculi is removed in a cat or dog, the decerebrate preparation thus obtained exhibits a systemic postural reflex with the following features . . . the dorsal muscles of the back, neck, and tail, the retractors of the head, and the elevators of the lower jaw, are all in harmoniously co-ordinated steady tonic contraction."

From this it may be seen that the muscles of the extremities show an alternation from axis towards periphery at the knee and hip respectively, and, in addition, this alternation is carried on in the axial muscles in which the dorsal group is over-active. The formula, therefore, for the limbs in decerebrate rigidity, going distally, is VDV, and the formula for the limbs and axial musculature, the axial being most proximal, is DVDV. These letters refer respectively to axis, hip, knee, and ankle. This experimental evidence is clearly cut, and forms the basis of a conception of muscular pattern in decerebrate states, to be illustrated later by case reports. Experimentally this pattern is more clearly defined than would be expected in the less uniform effects of human pathological processes.

B. The Clinical Evidence for Decerebrate Rigidity.—The first clinical description of decerebrate rigidity was given by S. A. K. Wilson¹¹ in November, 1920, a quarter of a century after the first experimental description by Sherrington. Wilson showed that a great variety of disorders, such as cerebral abscesses and tumours, cerebellar tumours, intraventricular hæmorrhage, acute purulent meningitis and ependymitis, tuberculous meningitis, hydrocephalus, congenital diplegias, chorea, athetosis, and dystonia lenticularis, could cause a picture resembling this or fragments thereof. A few quotations from his paper will suffice to give the movements affected.

Case 1 (p. 223).—"The arms were extended by the sides, slightly flexed at the wrists and notably rigid. The legs were also extended and adducted, with toes pointed down and in."

"11.45 p.m. About this time both arms became rigid, the left rather more than the right. Both were adducted at the shoulder and strongly extended at the elbow, with pronounced internal rotation and hyperpronation; the wrists were flexed, so that the palms of the hands looked up and out, quite turned away from the body." (*Fig. 2.*)

"1.25 a.m.—When the patient was seen again, after about an hour's interval, he was in the same extensor position, arms adducted at shoulders, extended at elbow, flexed at wrist, whole arm rotated inwards and hyperpronated; on the right the thumb was between the first and second fingers of the hand, but not on the left. The legs were rigidly extended, feet inverted, great toes dorsiflexed."

Case 2 (p. 227).—"The whole of the musculature of trunk, arms and legs became rigid; the arms and legs were extended to the fullest extent, the arms by the sides, ~~and pronated~~, while the hands were clenched and wrists slightly flexed. The legs were slightly inverted, the feet more notably so, with the toes pointing down and in."

*And the legs together in abduction both knees flexed
were strongly inverted & hyperpronated*

Case 3 (p. 228).—"The upper extremities were adducted and internally rotated, the forearms strongly hyperpronated, so that the backs of the hands faced each other; trunk and neck were extremely rigid and the latter slightly retracted; the legs were similarly in full extension, heels drawn up, toes pointing down and feet inverted."

Case 4 (pp. 229 and 231).—"A brief period of excitement and moaning ushered in the attacks, which consisted of sudden powerful opisthotonus and head retraction, the neck straightening and the occiput nearly touching the shoulders. The left arm relinquished its flexed attitude and became strongly extended, the forearm over-pronated, the wrist extended and the third and fourth fingers flexed, while the thumb was flexed into the palm. The legs were in fullest extension with heels up and toes down, and the right arm was as the left, except that it was rather less inverted and the hand was in the form of a fist. Trunk and limbs alike were absolutely rigid."

Case 5 (p. 231).—"March 6, 1906: The legs were now extended again, and so were the arms. The patient lay unconscious, with the arms extended by the sides and the forearms notably hyperpronated. The hands were clenched. The legs were also fully extended, with feet inverted and toes pointing down and in."

FIG. 2.—The typical decerebrate attitude of extension pronation.
(By kind permission of 'Brain'.)

Case 6 (p. 233).—"The arms were fully extended, adducted, strongly hyperpronated; the backs of the hands faced each other, and at the same time the wrist and finger flexors were conspicuously contracted; the neck was stiff from muscular rigidity, but was not retracted in any degree; the lower extremities were in full extension and adduction, with heels drawn up, toes pointing down, and feet slightly inverted."

Case 7 (p. 235).—"His arms went out in front of him, extended and hyperpronated, with hands clenched and wrists flexed."

When these descriptions are compared with the tables of movement given by Sherrington and with *Tables I, II, III, IV, and V*, it will be seen that the formula D—axis, V—shoulder and hip, D—elbow and knee, and V—wrist and ankle and below, is clearly present.

The quotations from Wilson's paper were chosen to illustrate clearly-defined patterns. Many of his descriptions, as would be expected from the character of the pathological process, were not so

precise. The lack of clearly defined pattern in many cases appears to us susceptible of easy interpretation, as indeed has been suggested by Wilson. In the cases which follow we have fortunately been able to find a precise formula in all but one. In the light of the neuromuscular approach, these formulæ become significantly indicative of curious and inexplicable patterns in other conditions.

C. The Clinical Evidence for the Flexion Reflex.—When the illustrations from Sherrington's article on "The Reflex Mechanism of the Step"⁹ are examined, it is seen that the flexor phase, or the flexion reflex element, forms a corresponding opposite to the anti-gravity position. "A complete flexion reflex consists of a single flexion at the hip and knee, with dorsiflexion of foot and toes."¹²

Reference to the tables added to these illustrations shows that the formula is D—hip, V—knee, D—ankle for the limbs, going distally, in contrast to the VDV of antigravity posture. Furthermore, it has been shown by Walshe,¹² Riddoch,¹³ and others that a well-marked contraction of the abdominal musculature occurs with the fully-developed flexion reflex. Therefore the formula becomes VDVD for the musculature of the limbs and trunk, and is in contrast to the DVDV formula of antigravity posture. These letters refer respectively to the axis, hip, knee, and ankle. *Case 5* described below (*Fig. 9*) illustrates this.

D. Summary.—From this it may be seen that, not only in decerebrate posture, but also in the corresponding opposite, the flexion reflex, an alternating formula exists in the extremities, which is not unexpected, after all, when one considers the optimum mechanical needs of appendages consisting essentially of three segments which must be folded up and extended. This alternation is also present when the axial musculature is included.

IV.—CASE REPORTS.

In the case reports given below, not only movements as such, but the rôle of individual muscles in causing these movements, have been repeatedly and most carefully observed. The axial movements, and all movements of the extremities, except those at the shoulder, are easy to analyze by observation and various clinical tests. Certain difficulties appear at the shoulder, due to the fact that both dorsal and ventral muscles bring about the same movement, notably internal rotation. These muscles are the pectorals of the ventral group, and the latissimus dorsi, subscapularis, and teres major of the dorsal group. However, it is very easy to palpate both the pectorals and the latissimus, and thus determine which of these large muscles is in action.

Case 1.—R. E. (Fig. 3).

History.—In October, 1919, at the age of 15, the patient was taken with a respiratory disorder manifesting itself as a cold and bronchitis, unassociated with expectoration. She complained of pain in the chest. She was treated at various hospitals and dispensaries. The respiratory symptoms cleared up, but the pain remained for almost a year, until Sept. 25, 1920. At that time she had been suffering from excessive drowsiness for a month. She complained of diplopia, headache, fever, drooping of the right eyelid, and dragging of the left foot. At Christmas, 1920, choreiform movements in the legs began which prevented her from sitting still. Two days later similar movements appeared in both hands, and, two days after that, in the neck and head. By this time the diplopia had disappeared, though ptosis and dragging of the left foot still persisted. On Jan. 21, 1920, she was admitted to Bellevue Hospital, where she remained for five months. Three months after admission the ptosis disappeared. While at Bellevue the movements were those seen in the kinetic form of decerebrate posture. A precise analysis of the muscles involved was not made at that time. It was noted then that the functional element was large. The underlying process, however, was felt to be epidemic encephalitis. After discharge from Bellevue and a brief stay at the Metropolitan Hospital, she was admitted to Montefiore Hospital, Sept. 29, 1921.

FIG. 3.—Note the adduction at the shoulders, the decerebrate position of the left arm, and the adduction at the hips.

Physical Examination.—At the present time examination shows bilateral ptosis, nystagmoid oscillation in the lateral plane, and weakness of the lower facial muscles on the right. Standing unassisted is impossible. There is no other involvement of the muscles supplied by the cranial nerves except the spinal accessory, which will be described under axial musculature.

Axis.—There is definite arching of the body with retraction of the head, simulating typical opisthotonus. She has shrugging movements of the shoulder which are produced by the action of the trapezius. The sterno-cleido-mastoid on the right contracts occasionally.

Upper Extremities.—The arms are adducted and rotated inwardly, and the pectorals can be felt to contract when this movement occurs. There is no contraction of the latissimus, the deltoids, rhomboids, or spinati muscles. The forearm is extended on the arm by the triceps, and the wrist is pronated and flexed. While at Bellevue it was noted that the fingers were consistently flexed and adducted during the movements, while here the first finger is extended. The present finger movements imitate classical athetosis.

Lower Extremities.—In the lower extremities there is a constant movement of what appears, on first analysis, to be flexion, and what really is a spasmodic adduction, of the thighs due to definite contraction of the adductors. Occasional contraction of the pectineus is felt (supplied by both

dorsal and ventral nerves). When the legs are abducted there are active adductor movements which bring the legs to the mid-line. During this movement flexion at the hip does not occur. The iliopsoas, sartorius, tensor fasciæ latae, and glutei do not contract. When the patient is on her abdomen and the knee is flexed at right angles, rhythmic extension movements produced by the quadriceps occur. When she is on her back the hamstrings can be felt to contract. This does not produce flexion at the knee, but rather slight extension at the hip. Rhythmic movements accentuate a rather mild equinovarus position. The toes are flexed in this movement.

Summary.—Of the muscles which could be tested, the following are found active and producing movements:—

1. AXIAL

Extensors of the head, neck, and back

Trapezius

Right sterno-cleido-mastoid

2. APPENDICULAR

a. Upper extremity

1. Shoulder Pectorals

2. Elbow Triceps

3. Wrist Flexor group

Pronators

4. Fingers Long flexors

Extensor indicis proprius

Adductor and flexors of the thumb

Volar interossei and lumbricales

b. Lower extremity

1. Hip Pectineus

Hamstrings

Adductors

2. Knee Quadriceps

3. Ankle Gastrocnemius

Soleus

Tibialis posterior

4. Foot Long and short flexors

Abductors

With the exception of the sterno-cleido-mastoid, only dorsal axial muscles come into play. Movements at the shoulder and hip are brought about by ventral muscles, those at the elbow and knee by dorsal muscles, those at the wrist and ankle by ventral muscles. In the fingers and toes the movements are ventral except that of the extensor proprius.

Diagnosis.—Epidemic encephalitis, choreic and kinetic type.

Case 2.—L. R., age 13 (*Figs. 4 and 5*).

History.—The patient was admitted to the Montefiore Hospital on April 8, 1922. The history obtained from the mother was that the child had not been well for about two years. She was irritable as a rule, easily disturbed, and fainted frequently. The mother believes she may have been feverish at times. There is no history of diplopia (?) In February, 1922, she was brought home because movements of the limbs, head, and trunk had begun. After staying a month in another hospital she was admitted to Montefiore Hospital.

Physical Examination.—On first sight she presents the picture of chorea. The arms, legs, and head are moving almost continually. The

duration of the movement is less than a second when timed by a stop-watch. More careful observation shows that certain definite groups of muscles are

FIG. 4.

brought into activity, thus producing a continual repetition of the same postural patterns. When the patient is asleep there are no abnormal positions or postures. With the exception of the movements noted, the physical examination is quite negative. The cranial muscles are negative except for those supplied by the spinal accessory, which will be mentioned below.

Axis.—The extensors and rotators of the head bring about retraction and rotation. Slight opisthotonic movements are occasionally noted. When the patient is more excited, these movements become more pronounced. The trapezius and sterno-cleido-mastoid are occasionally contracted on both sides. With the exception of this latter muscle, no activity of the ventral muscles of the axis has been noted.

Upper Extremities.—When the patient is relatively quiet, the pectoral group at the shoulder adducts and internally rotates the entire arm. As the series of moving pictures shows (Fig. 4), this movement alternates with one of rest. At the elbow the triceps extends the arms. At the wrist the flexors are in action as well as the pronators. The flexors of the fingers and thumb, as the photograph (Fig. 5) and moving picture show, are also in action.

It may be seen from this that there is an alternation of activity of ventral and dorsal muscles, the formula of which is at the shoulder ventral, at the elbow dorsal, at the wrist and below ventral.

Lower Extremities.—The legs are carried forward and across the mid-line by the ventral adductor group. The iliopsoas is not in action, as can be plainly made out on examination. When the legs are widely spread, flexion at the hip is not seen; instead, the legs are adducted. Extension at the hip by the hamstrings is also present. The gluteal group of muscles is not in action except when the axial muscles are bringing about opisthotonus. At the knee the hamstrings produce no flexion; on the contrary, the dorsal quadriceps group extends. At the ankle the gastrocnemius and soleus and tibialis posticus produce extension, and the

flexors of the toes are active. As reference to *Table III* will show, this last is entirely a ventral action.

The formula for the leg is therefore identical with that of the arm—at the hip ventral, at the knee dorsal, at the ankle and below ventral. When the patient's movements become excessive owing to excitement, the pattern ceases to be so precise, and other muscles begin to contract. These muscles are the antagonists of those noted above. This is a relatively rare occurrence.

Summary.—The patient shows activity of the dorsal musculature of the trunk, and an alternating formula for the extremities. The only exception is the sterno-cleido-mastoid. Occasionally the antagonists of these muscles go into action.

Diagnosis.—Epidemic encephalitis, choreic and kinetic type.

FIG. 5.

Case 3.—J. S., age 17 (*Figs. 6 and 7*).

History.—This patient was admitted to the Montefiore Hospital on May 1, 1922. She has had a rather stormy career, but despite family opposition had worked hard in pursuing her studies at high school. She graduated in January, 1920. She then studied at a business school, graduating at the head of her class. She began stenography, and since has done exceptionally well.

Between January and July, 1920, she began to feel tired and sleepy during the day, and restless at night. She could not sleep well. In July, 1920, she went to the country, but did not improve, and so returned home after two weeks. In August, 1920, she had pains in her legs, with fever, lasting one week. In January, 1921, there occurred a family quarrel centred about a sexual affair, and followed by a disturbed night. In the morning she noticed movements of the hands, feet, and head. She could not talk. Some improvement occurred, but two days later diplopia and fever were present. She soon became delirious, and was admitted to the Lenox Hill Hospital, where she stayed three months. After a stay in the country her general condition improved. In May, 1921, after an attack of vomiting associated with abdominal pain, she was admitted to Bellevue. Following this her movements were intensified, and she was admitted to the Neurological Institute, where she remained nine weeks. There was considerable improvement, but she continued to attend the dispensary until February, 1922. In March, 1922, she entered Mt. Sinai with abdominal pain and depression. She became very noisy and excited, and was occasionally confused, especially at night. She finally left the hospital and was admitted to Montefiore Hospital May 13, 1922.

Physical Examination.—On first observation the patient's condition suggests chorea. The extremities and head are moving continually. These movements are not so pronounced when quiet and unobserved. The emotional reaction resultant upon examination intensifies the movements. Careful observation shows that the activity of certain groups of muscles predominates and produces a repetition of the same postural pattern.

Cranial Nerves.—When the patient is quiet, the motor cranial nerves are also at rest. When excited, there is frequent grimacing, the tongue is protruded straight forward and to the right and left.

Axis (Fig. 6).—There are opisthotonic movements. The head is pulled backward, the spine is curved. The patient states that sometimes

FIG. 6.

FIG. 7.

this begins at the neck and passes wave-like to the end of the body. At other times either the neck region or the lumbar region is alone affected. The trapezius is found active on both sides, but more so on the right. It elevates the shoulder at times. The sterno-cleido-mastoid on the right is sometimes in action, though rarely. The lower ventral trunk muscles (abdominals) occasionally contract, but never bring the body forward.

Upper Extremities.—Some of the shoulder muscles are active. The scapula is moved out and up. On analysis this is found due to the trapezius and to internal rotation by the pectorals. The deltoids and rhomboids are never in action. Occasionally a contraction of the latissimus dorsi is observed. The triceps is almost always contracted, the elbow flexors are rarely so. Flexion occurs at the wrist, though extension is also observed at times. Pronation is frequently noted, but supination also

occurs, though less often. When extension is present supination is noted also. The fingers do not show as typical or as constant a response as that which occurs in *Cases 2 and 4*.

Lower Extremities.—The dorsal muscles at the hip do not take part in any of the movements. The patient states that her leg is never carried forward, either when standing or in bed. None of the following muscles contract in any of the movements: iliacus, psoas major and minor, pectineus, sartorius, and tensor fasciæ latae. The glutei do not contract while standing or when on the abdomen or back. The adductors are powerfully active, and may be felt when prone, supine, or standing. This movement appears one of flexion, but is not in the dorsoventral plane but at an angle tilted towards the mid-line. When the patient is on her abdomen, extension at the hip is produced by the hamstrings, while the glutei are definitely relaxed. The patient states that her leg is twisted inwards (inwardly rotated). She does not confuse this with inversion of the foot. The leg is continually held in extension, and never when standing or prone goes into flexion. The feet are inverted, the right one more so than the left, and extended so that the dorsum of the foot is almost in a straight line with the long axis of the tibia. When standing, both feet are inverted, the right much more than the left. When walking, the external lateral border of the foot is turned to the ground owing to inversion (*Fig. 7*). This can be momentarily overcome, but immediately returns.

Summary.—In this case of epidemic encephalitis there is a well-defined picture showing a rhythmic recurrence of opisthotonus and the antigravity posture. When the patient is quiet this is easily made out. When excited there is overflow into the opposite pattern, though even then it occurs much less frequently than that of the antigravity posture.

Diagnosis.—Epidemic encephalitis, choreic and kinetic type.

Comments on Cases 1, 2, and 3.—The diagnosis in the three cases is epidemic encephalitis of the kinetic and choreic types. It is extremely interesting that at one time or another each of these three cases was diagnosed as hysteria. The hysterical element, or what might better be considered functional overflow, is marked. Were it not for the findings in the case of R. E., namely, paresis of one leg, persistent and partial ptosis of both eyelids, diplopia, nystagmus, headache, and fever; for the prolonged illness in L. R., with fever and delirium; and the insomnia, fever, diplopia, and intestinal and bladder disorders in J. S., these three patients could be considered as hysterics. However, it is now well known that the lesions of epidemic encephalitis not only produce pictures which are subject to great exaggeration by mental factors, but that the disease may be practically latent until mental shocks occur. There is no difference, in the effect of physical and psychic trauma in bringing this disease to light, from what familiarly occurs in diseases of the nervous system, such as paralysis agitans and tabes dorsalis.

The Muscular Element.—In all three cases the muscles involved in producing the patterns described were almost identical. Indeed, if it were not for a few exceptions, the descriptions of any one of the

three cases would fit the others. In all of them the dorsal axial muscles were instrumental in causing movements. In all of them the muscles described by Sherrington, and then by Wilson, as producing patterns of decerebrate posture, were in action. It is extremely interesting that those muscles which are engaged normally in maintaining an erect posture should appear as clearly as they did. The formula for the arms and legs was, in all three cases, ventral movements at the hip and shoulder, dorsal movements at the knee and elbow, and ventral at the wrist, ankle, and below. In addition, the ventral axial sterno-cleido-mastoid muscle was active in all three cases. We are unable to explain this to our satisfaction, but feel that it may have to do with separate control by the nervous system of cephalo-rotatory movements. Further study of this matter will have to be made.

The alternating formula VDV of the extremities was complicated in *Cases 2* and *3* by the appearance of a reverse formula, DVD. Occasional abduction of the arm and flexion of the elbows was seen (*Cases 2* and *3*). More frequent than this were movements of extension and supination at the wrist (*Case 3*). These movements were carried out by dorsally innervated muscles. Further discussion of this flexion reflex formula in the arm appears in Section V.

The movements of the fingers in L. R. and in R. E. in the earlier periods of their illness were definitely flexor. Later on, some of the finger movements involved extension at the metacarpophalangeal joints. In J. S., movements of extension and flexion were somewhat mixed. That this was not unexpected will be later referred to in Section V, where the finger movements in both the antigravity and flexion reflex arm postures receive more attention.

Case 4.—Herbert S., age 28 (*Fig. 8*).

History.—The patient, a cutter, was admitted to Montefiore in April, 1921, and died in October, 1921. He was admitted with the following history. Following a 'cold' in October, 1920, which was associated with gastro-intestinal symptoms, there occurred thermo-hypæsthesia in the lower extremities. Both legs below the knees felt cold when taking a warm bath. A week later stiffness of the left leg occurred, and the next morning dribbling of urine. He then entered the Neurological Institute, and after three weeks noticed some improvement. Soon after, fever developed— 101° to 104° —associated with swelling of the left elbow. This lasted three weeks. Following this he was unable to walk or stand, though he could move his feet in bed. At this time the sphincters were more severely involved, with bladder incontinence and retention of fæces. Two weeks prior to admission he again had a temperature for two days, and could not move either his arms or his head. This was associated with pain in his left shoulder and side.

Physical Examination.—The patient is confined to bed and unable to move unaided. The motor cranial nerves are normal. There was, however, in a previous examination, slight right central facial palsy. The head

is rigidly maintained in a normal position when lying down, but when sitting up he can both hold it up and move it in all directions. He is unable to maintain a sitting position by himself, owing to paralysis of the axial musculature.

Upper Extremities (Fig. 8).—Voluntary movements in the upper extremities are lost, with the exception of movements which carry the arms from a horizontal position upwards from the bed. Flexion and extension of the fingers of the right hand, and flexion of the fingers in the left hand are also absent. The arms are rigidly ~~contracted~~ ^{extended}. The pectoral muscles pull the arms forward to the chest. They are very hypertonic. The arms are held extended ^{on the elbows by the biceps} ~~on both sides~~. On the right the biceps shows normal tone, while on the left it is extremely hypertonic. On the right the forearm is pronated so that the ulnar border of the hand faces directly upward. On the left this pronation is only carried to an angle of 45° to the horizontal plane. On the right the wrist is flexed to a right angle. The fingers are forcibly extended at the two terminal phalangeal joints. When flexed by the examiner they returned to the extended position with an elastic-like bound. The thumb is adducted and slightly flexed at the proximal joint. The fingers are adducted. The left hand is *extended* at the wrist, nearly at right angles, while the fingers are flexed at the first interphalangeal joint. The gradation of flexion passes from about 5° at the index finger to 90° at the little finger. The thumb is flexed at the proximal joint and adducted into the palm. The position of the left hand is much like that due to the associated movements resultant upon making a fist, that is, flexion at the fingers and extension at the wrist.

Lower Extremities.—These are both rotated so that the lateral plantar borders of the foot rest upon the bed. They are flaccid, and present only the defects due to loss of tone and voluntary power, notably flexion of the toes and of the sole of the foot, with extension at the ankle (pes cavotinus).

Sensation.—Lost from the third dorsal segment downward.

Reflexes.—The jaw-jerk is extremely lively. The deep reflexes are not obtained in the arm. The abdominal reflexes are absent. The knee-jerks are diminished.

FIG. 8.

Throughout the examination the patient showed 'flexor spasms' of the legs. The slightest stimulus caused this retraction. It has been necessary to hold the patient's legs down by a sheet to prevent these seizures. Once during the examination, reflex priapism was noted. Control of the bladder is lost.

Spinal Fluid.—This shows the following: increased pressure; globulin +++; flocculent precipitate; reduction to Fehling's diminished; cells 70.

Wassermann.—Blood and spinal fluid negative; blood culture and spinal fluid negative.

Urine.—Negative.

Summary.—The patient presented a varying course, and finally died a bulbar death. He ran a septic temperature throughout his stay in the hospital. A diagnosis of severe infective meningo-encephalomyelitis was made. The flaccidity of the legs and the sensory changes from the third dorsal segment downward, coupled with the reflex spasm, reflex priapism, and reflex incontinence, indicated a very severe lesion in the upper dorsal cord. The extremely spastic paralysis of the arm muscles, the transient facial palsy, and rigidity of the neck indicate that the process involved higher portions of the neuraxis.

Comments.—We have used this case to illustrate a static hyper-tonic condition in the upper extremities, showing difference in posture on the two sides. Though the condition of the lower extremities is pertinent to the subject of this paper, we shall leave a discussion of this matter for the next case. The points which we wish to emphasize are that: (1) The state of the upper extremities was unchanged for a considerable length of time. (2) No choreic movements were present. (3) The asymmetry in the two hands, as showing in *Fig. 8*, was very striking. It indicated that the process must have involved slightly different centres as far as the forearm and finger muscles were concerned. On the side in which pronation was most marked, flexion of the wrist was complete. On the side where pronation was relatively slight, extension at the wrist was present.

Case 5.—Harry S., age 36, metal worker (*Fig. 9*).

History.—The patient was admitted Sept. 29, 1921, to Montefiore Hospital, complaining of weakness in both limbs, constipation, and difficulty in passing urine. In August, 1919, he complained of 'stomach trouble', which consisted of pain in the 'stomach' and a feeling of a constricting band around the abdomen. In May, 1921, he noticed pain in the knees, which in a few weeks crept upward to his hips. It was more intense on the left than on the right. This pain remained, and in July he experienced what he describes as a 'freezing sensation and pins and needles' in the soles of his feet. Simultaneously weakness was noticed. A lumbar puncture was done, after which he lost the power of using his legs completely. Urgency of urination appeared, as well as constipation, more marked than before. In the early part of August his legs began to stiffen in extension, and grew progressively worse.

Physical Examination.—On admission, the cranial nerves were negative. The deep reflexes in all the extremities were exaggerated. The upper abdominals were present, the left lower easily exhausted and the right not

obtainable. There was marked spasticity of the lower extremities. Knee- and Achilles-jerks were hyperactive. There was bilateral ankle-clonus, with a Babinski on the left, questionable on the right. Sensory loss from D7 downward existed. He always lay with the lower extremities in extension until after the operation performed by Charles Elsberg on Nov. 26, 1921. *After the operation* the abdominal muscles contracted, the thigh was flexed on the hip. The muscles taking part in the contraction were the whole femoral group. The foot was at right angles to the leg (*Fig. 9*), the entire picture representing the flexion reflex described by Walshe¹² or the nociceptive reflex of Sherrington,⁹ or paraplegia in flexion described by Babinski. Knee- and ankle-jerks were active.

Part of Elsberg's operative notes follow: An extradural tumor was found lying mostly on the the posterior aspect of the dura and extending beneath the 4th, 5th, 6th, 7th, and 8th dorsal vertebrae. A large amount of it was excised, but fragments remained in various places in front of the

FIG. 9.

dural sac. There was no doubt that there was more tumor below the parts exposed.

Diagnosis.—Endothelioma (?).

Comments.—This patient showed typical hypertonic paraplegia in extension before operation, and typical hypertonic paraplegia in flexion after it. The increase of tone was as great after the operation as before. This indicates clearly that tone flows into pattern. Pattern changed in this case from that of the antigravity reflex to that of the flexion reflex. The tumour being cervical, it must have damaged the control of *lower* integrations. This indicates that the pattern of decerebrate posture of the legs must be carried out by neurones lying within the spinal cord. The presence in the legs of decerebrate rigidity is almost an exact counterpart of an experimentally-produced picture. Why the corresponding opposite pattern developed after operation is not clear. The case illustrates the

successive static fixation of two spinal patterns of opposite muscular formula.

V.—THE FLEXION REFLEX POSITION IN THE ARM.

Up to now emphasis has been laid upon the formula for the legs in the corresponding opposite positions of antigravity posture and the flexion reflex. This has been examined in the light of the experimental work of Sherrington and the clinical work of Wilson and ourselves. For the arms, the formula for the position corresponding to the antigravity position in the legs has been illustrated in the case reports and discussion. However, the position in the arms which would correspond to the flexion reflex element in the leg has not been defined. This, as would be expected, would present a formula opposite to that of the decerebrate arm—notably, dorsal at the shoulder, ventral at the elbow, and dorsal at the wrist. In the course of our investigation of this matter a lengthy paper by Riddoch and Buzzard,¹⁴ which considered this subject, came to our attention. They describe a flexion reflex of the upper limb as follows: “The reflex response, for which the convenient term is ‘flexion of the upper limb’, was readily obtained in No. 5. On scratching the palm of the paralyzed hand there occurred *flexion of (the) fingers*, wrist, and elbow, slight abduction and external rotation of the upper arm, and elevation of the shoulder. These were the main components of the general response, which varied in details according to the situation of the stimulus within the receptive field” (p. 434). However, in another place (p. 421), in describing associated movements following stimulation, the effect upon the upper limbs is given as follows: “The upper limbs became rotated outwards at the shoulders, flexed at the elbows, *extended at the wrists with slight supination of the forearms; the fingers became extended at the metacarpophalangeal joints and flexed at the interphalangeal joints, while the thumbs were extended and abducted*”.

An analysis of this long paper will not be made here. Suffice it to say that, if the formula for the ‘extension reflex’ or the antigravity posture is VDV, as is indicated clearly by the findings of Wilson, Riddoch and Buzzard, and ourselves, it would be presumed that the corresponding opposite to this would have an opposite formula and would conform to the movements described in the quotation last given. It would be expected that there would be abduction at the shoulder, flexion at the elbow, extension at the wrist and at the metacarpophalangeal joints. This brings up a matter of considerable importance in the analysis of reflex patterns of the limbs which bears not alone on the question of the upper extremity, but also upon the Babinski reflex and its associated phenomena in the lower extremities. The Babinski phenomena will be given special consideration in another paper.

The intrinsic muscles of the hand are all of ventral origin. Adduction and abduction of the fingers, extension at the phalangeal joints, abduction and adduction of the thumb and little fingers, are all brought about by these ventral muscles. When, therefore, there occurs activation of a pattern which demands a dorsal reaction in the long muscles acting on the wrist and fingers, and when the impulse activating this pattern flows into the intrinsic muscles of the hand, no dorsal intrinsic muscles are there. In the antigravity position the long flexors of the wrist and fingers *and* the intrinsic muscles of the hand are activated (ventral muscles). In the flexion reflex element the long extensors of the wrist and fingers (dorsal) are activated, while the intrinsic hand muscles (ventral) are not. *Is w* This ~~last produces~~ extension at the wrist, extension at the metacarpophalangeal joints, abduction of the thumb, and, in some instances, extension of the phalanges. Contraction of the extensor digitorum may produce this, depending upon the strength of the stimulus. Consequently the typical picture may include either extension or flexion at the phalangeal joints. The long flexors of the fingers are not active in producing flexion, the volar interossei and lumbricales are opposed by the extensor digitorum communis, the adductor of the thumb by the ~~short and~~ long abductor. *x x*

The postural pattern of the flexion, ~~at the hand~~ ^{of the arm} consists therefore of dorsal activity at the shoulder, ventral activity at the elbow, and dorsal at the wrist and fingers.

At the shoulder the large number of dorsal muscles makes it possible to have a number of different reactions. The following from Riddoch and Buzzard¹⁴ indicates the appearance of the reaction which we have just defined, and also the possible variations: "The movement most commonly obtained consists of adduction and external rotation at the shoulder, flexion at the elbow, and extension of the hand and fingers, but the response varies in a remarkable manner with alternation in the locality of the stimulus. Thus, when the reaction is excited by scratching the palm of the hand, the movement at the shoulder is abduction and retraction of the upper arm. Stimulation of the back of the forearm yields adduction at the shoulder, and of the inner aspect abduction at this joint. Again, when the stimulus is applied to the skin over the deltoid, the response is mainly strong elevation of the shoulder with adduction and external rotation of the upper arm" (pp. 437, 438). This emphasizes the variations found.

The pattern which we have described appeared in *Case 3* (J. S.). It occasionally followed or alternated with the antigravity posture. This represents the alternating stepping movements (reflex walking) produced experimentally by Sherrington. It has also been seen in

a man suffering from spastic tetraplegia, shown at autopsy to be due to pressure upon the lower brain-stem of an apricot-sized aneurysm of the right vertebral artery.

In the movements of athetosis, dystonia lenticularis, and chorea, these patterns, often fragmentary, can be made out, as Wilson has emphasized. The positions sometimes change so rapidly that it is only by means of successive cinematographic pictures that the analysis can be made.

VI.—THE RELATION OF POSTURE PATTERNS TO TONE.

In this paper it is assumed, that not only the integration which produces the flexion reflex, but also that producing the corresponding opposite pattern, notably the pattern of antigravity posture or reflex standing, is entirely spinal. In order to defend this assumption it will be necessary to consider some of the experimental work undertaken in producing decerebrate preparations. Sherrington⁹ states: "This reflex standing disappears when the transection of the brain is made behind the posterior edge of the pons", and "the experiments of Horsley¹⁵ and Thiele show that decerebrate rigidity is hardly seriously impaired by successive sections of the cerebellar region until the paracerebellar nuclei are invaded". Wilson,¹¹ in his paper on decerebrate rigidity in man, states in discussing the pathogenesis of this condition: "In the first place there is general agreement that decerebrate rigidity makes its appearance after transection of the neuraxis at the level of the anterior colliculi, and disappears by a second section below the neuronie level of the medulla". Sherrington⁹ has stated: "When in the dog the spinal cord is severed in the thoracic region, the hind-limbs cannot at first stand; but after lapse of weeks or months they exhibit this power. That is, with hind-feet on the ground the reflex tonus of limb-extension suffices to bear the weight of the limbs and superincumbent hind-quarters. The attitude thus exhibited indubitably amounts to standing, and is sometimes maintained for minutes at a time".

It would appear from these four quotations that, in the first place, removal of the central nervous system down to a point "behind the posterior edge of the pons" still permits the existence of reflex standing or antigravity posture, and the fourth quotation above indicates that this same reflex position may be obtained in an animal whose cord has been transected in the thoracic region. It is furthermore true that *no difference results in the pattern obtained when the brain is transected successively from the anterior colliculi to a "point behind the posterior edge of the pons"*. In other words, no change in pattern is produced by such successive removals of brain tissue. When a section is made below the point at the posterior edge of the

pons, or, to use Wilson's words, the "neuronic level of the medulla", the rigidity disappears. But this is due to a transitory loss of tone, as has been suggested by both Sherrington and Wilson, caused by the removal of the grey matter in the regions between the pontine section and the spinal section. However, as the above quotation of Sherrington notes, after a lapse of time the antigravity posture pattern reappears, even in decapitated animals.

Since the pattern definitely exists when all portions of the brain stem above the pons are removed, the neurones producing it and released by the removal of higher centres must lie in the intact portions of the nervous system, that is, in the spinal cord and small portions of the medulla. A further proof of this is that section of the cord at the thoracic level allows the same antigravity pattern to remain in the segments below.

Tonic influences which activate muscles in this particular pattern appear to lie both in the medulla and in the afferent fibres of spinal nerves. If either or both of these influences are removed, there ensues a period during which the pattern disappears and flaccidity results. However, the following quotation from Graham Brown¹⁶ indicates that proper stimulation from above may still activate the pattern: "The reactions (of decerebrate attitude) may occur many months after division of the dorsal spinal roots of the arm. That is to say, appropriate stimulation in the region of the mid-brain may evoke an extensor postural tonus or a flexor postural tonus. Sherrington has found that the decerebrate rigidity which occurs after removal of the cerebrum does not occur in a 'de-afferented' limb, but the fact that a condition which at any rate very closely resembles this state may be evoked in such limbs seems to point to the conclusion that the absence of this postural tonus in the decerebrate 'de-afferented' animal is due to the failure of the ascending impulses from the limb which normally play—however, indirectly—upon these mechanisms of the mid-brain, and that the mechanisms themselves, if properly activated, are still able to induce the tonus".

Pattern and tone constitute two different entities in the nervous system. Tone is the common factor of hypertonic states, and activates muscles in various patterns. The experiments of Graham Brown (decapitation and de-afferenting) indicate this. When tone is removed, the pattern, like a picture on the wall of a dark room, is not seen but is none the less there in spite of the fact that it is not activated. In brief, tone flows into moulds of patterns much as an electric current ~~flows~~. Just as a galvanic current activates flaccid muscles, so does tone, but in addition, it activates them in pattern. x

From a consideration of the muscles involved in the flexion and extension phases of gait, as shown by Sherrington, and from all the

work on reciprocal innervation, it would be assumed that the neurones for the flexion reflex integration and the reflex standing integration, being corresponding opposites, would be located in the same portions of the nervous system.

From the point of view taken in this article, based upon a neuromuscular conception of movements, the same conclusion can be drawn. From an evolutionary point of view a similar hypothesis must be formulated. When, in the course of evolution, an animal with singly-hinged, fin-like appendages developed appendages with three joints showing the corresponding opposites, the reflexes of flexion and of antigravity posture, it would be natural to assume that the neurones regulating these two newly-appearing reflex activities would lie in the same portions of the nervous system.

VII.—THE KINETIC AND STATIC TYPES.

The spinal neurones must be activated, or no pattern would be present at all.

In the kinetic types described, the choreiform movements produced the patterns with great consistency. The muscles of the opposite group contracted occasionally (*Cases 2 and 3*). In some cases the kinetic impulse, flowing into lower centres, may produce an apparently patternless picture, as is frequently seen in chorea. These movements, due to their speed, are patternless on ordinary observation, but can, by means of analysis by successive moving pictures, be resolved into definite patterns. In our cases an integration having a clearly definite pattern was exposed to the kinetic impulse. When the opposite of this pattern was activated, it indicated that corresponding opposites were both exposed to the kinetic impulse. Indeed, in reflex stepping we see such a combination beautifully illustrated. Since these opposites constitute a pair of neurone arrangements of the same phylogenetic age, it is natural to find them closely associated.

In the purely spastic variety, *Case 4*, it was found that the tone overflowed not only into those muscles which determined the pattern (triceps), but also into the opposing muscles (biceps). Nevertheless the pattern remained. It would appear, therefore, that though this tone was distributed to antagonists, *it was distributed subject to pattern. This serves to emphasize the fact that tone flows into pattern and constitutes a separate entity in the nervous system.*

VIII.—SUMMARY AND CONCLUSIONS.

Abnormal movements and positions are customarily described as such without naming in addition the muscles which produce them. There the matter is allowed to rest for all practical purposes—"the

arm and hand are flexed"—“the arms are adducted, the elbows extended, the wrist and fingers flexed”. True, certain formulæ for movements exist, such as the flexion of the arm and the extension of the leg of hemiplegic contracture, but the *anatomical relations* of the muscles and nerves causing such groups of movements have never been seriously considered in clinical neurology. Therein lies an error of omission. To draw conclusions about the nervous system from descriptions of movements and positions alone is an error of commission.

In this paper it has been shown that there is a well-defined grouping of nerves and muscles under integrating control of the spinal cord, and that it is on the basis of this grouping that formulæ expressing disease in certain parts of the central nervous system of man must be built.

The question of classification of spinal integrations is too lengthy to append here. Suffice it to say that the dorsoventral integrations of the axis (opisthotonic, emprosthotonic) and appendages (rod-like movement of the leg in walking), and the alternating VDV-DVD integrations of the appendages, are those concerned in stepping.⁸ In these formulæ the three initials describe respectively the type of movements at the hip and shoulder, knee and elbow, wrist and ankle and below. The alternating formula VDVD-DVDV, which includes both the axis and appendages, is made manifest by decerebration, as we have shown.

To say, in describing the antigravity posture of decerebration, that the leg is *extended* at the hip, knee, and ankle, the foot *adducted*, and the toes *flexed*, gives no notion of plan or order. To say that there is *adduction* at the shoulder (though *extension* at the hip), *extension* at the elbow, *flexion* and *pronation* at the wrist (though *extension* at the ankle), gives no notion of plan or order. When the facts relating to the grouping of nerves and muscles, not of movement alone, are inserted into the analysis, it is found that the leg and arm formulæ are the same—VDV—and there appears a simpler plan.

Similarly, when the corresponding opposites are considered, the so-called ‘flexion reflex’ of the arms and legs, there results the same confusion from a consideration of movements alone. The lower limb is *flexed* at the three great joints, the toes are *extended*, the arm is *abducted* (though the hip is *flexed*), the elbow *flexed*, the wrist *extended* (though the ankle is *flexed*). Here again clearness results from using what is really old information, the greater part of which may be found in such text-books of anatomy as Quain⁵ and Cunningham³. The formula for both arm and leg is DVD, and is opposite to that of the antigravity posture.

The integrations of the spinal cord have clearly defined patterns.

By virtue of their activity certain muscles always act together and in the same general way. Their activity may be recognized not only by inspection and palpation, but by changes in position.

The activating forces of these patterns are two—one kinetic and the other static. The latter is familiarly spoken of as tone. Either of these forces activates muscles in clearly defined patterns, provided that a group of integrating neurones is completely released. When a particular integration is patchily involved, such pictures as those of *Case 4* result. In any event, neurones causing pattern and neurones causing tone are not the same.

From the points of view of the physiologist and the pathologist, it is of some importance to recognize that the pattern for the trunk and appendages in decerebration is resident within spinal neurones. It represents the ^{highest} spinal integration. The fact that it may appear when lesions are produced as high as the anterior colliculi makes it seem probable that, between that level and the upper level of the spinal cord, ^{neurones for} posture patterns for the trunk and appendages as such, and different from those of the spinal cord, do not exist. These high lesions simply release the spinal patterns.

Integrations—as, for example, those of the proprioceptive system (labyrinth, cerebellum)—do exist above the upper level of the spinal cord.

Building upon the embryological grouping of nerves and their end-organs, the muscles, we have gradually come to see an increasing complexity of neurone patterns or arrangements, a manifestation of evolution, of which the dorsoventral integration of progression by hip and shoulder movements (tetrapodal animals) forms one stage, and the folding and unfolding DVDV and VDVD integration made manifest in stepping and in decerebration forms another and later stage.

With a clearly-defined notion of this and the other simpler spinal integrations established, the study of supraspinal integrations of movement and posture and their significance becomes possible.

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