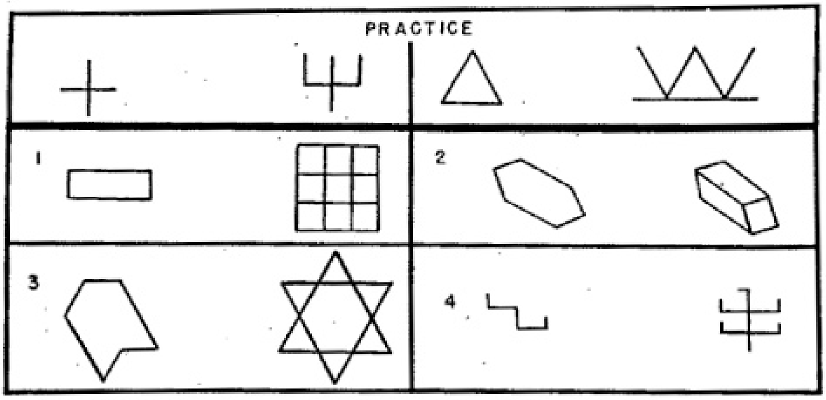

Fig. 3. Hidden-figure test adapted for children by Ghent (1956).

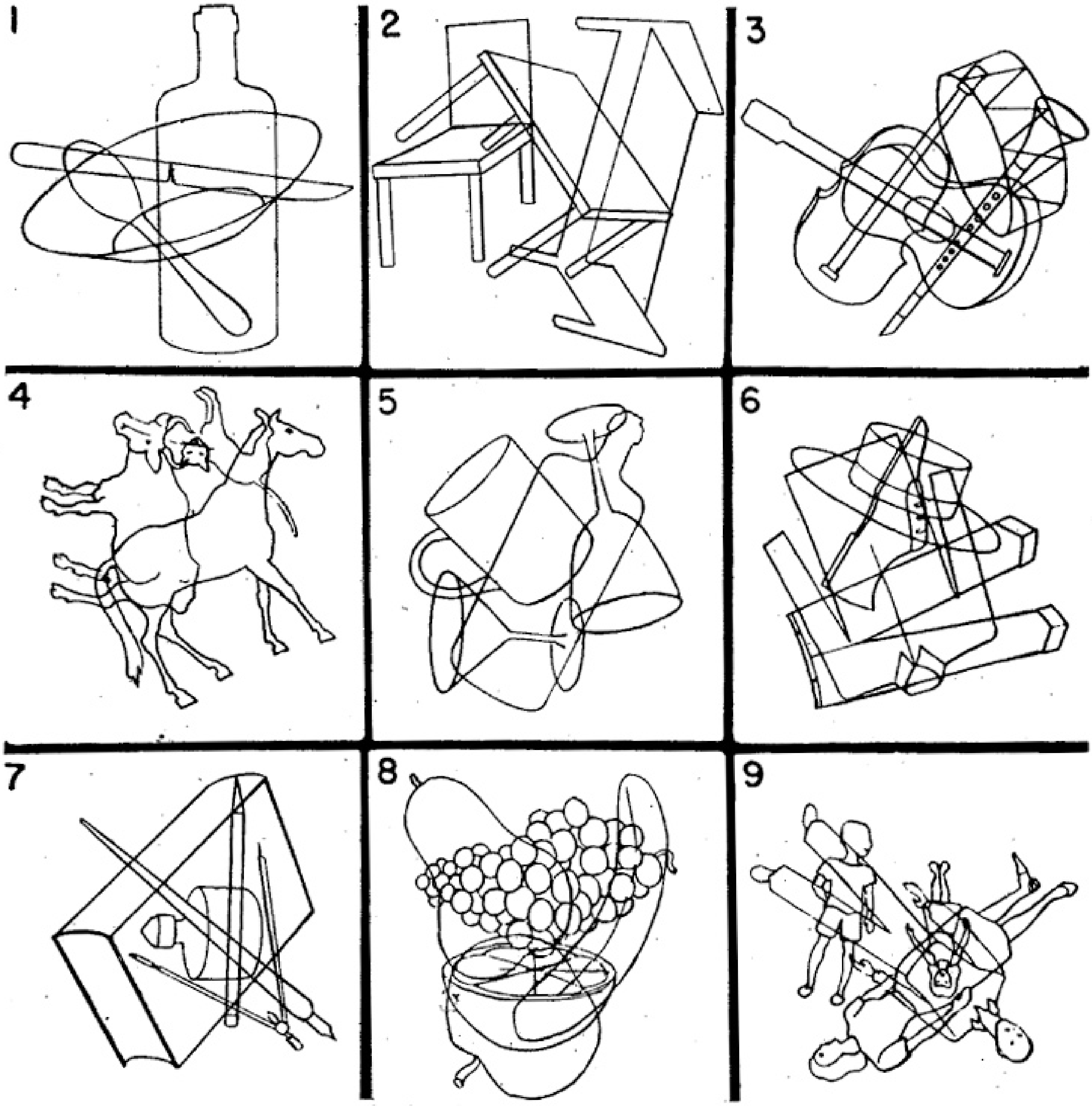

Fig. 4. Mixed-figure test for children.

Localisation during Body Tilt

We can illustrate this point by considering perceptual tasks which bring out general or specific effects of brain injury in adults, depending on how one analyses their responses. By appropriate analysis of performance we could demonstrate the coexistence of specific and nonspecific effects of brain injury, on the same task and in the same group of adult patients. We then plotted the developmental course of this function in normal children and its pathological counterpart in children with cerebral palsy. The latter group, of course, has lesions that are difficult to localise, but we were able to see whether normal and pathological development differed for effects that were specific for damage in a particular area, as compared with effects that were symptomatic of brain damage anywhere in the brain.

Visual Tasks

The perceptual task used with adults with brain injuries and with peripheral nerve injuries involved the setting of a luminous line in the dark during body tilt (Teuber and Mishkin 1954). Aubert described similar studies (with normal subjects) in 1861. Fig. 5 shows the chair in which the subjects were seated. The chair could be tilted 28° to the left or 28° to the right; 1.5 metres in front of the subject was a luminous line which the experimenter could tilt 30° to either side. Each man was placed in the tilting chair in a completely dark room, and was asked to set the luminous line to the vertical, first with body and head upright and then with body tilted to the left and to the right.

Generally, when an adult is tilted about 30° to the left or right (see Fig. 6) he tends to make constant errors in setting the luminous line, and these errors depend on the direction of his tilt. When tilted to the left, he tends to displace the luminous line to his right, and conversely. When seated upright, the errors are quite small. In this last respect, there was no difference between brain-injured adults and controls.

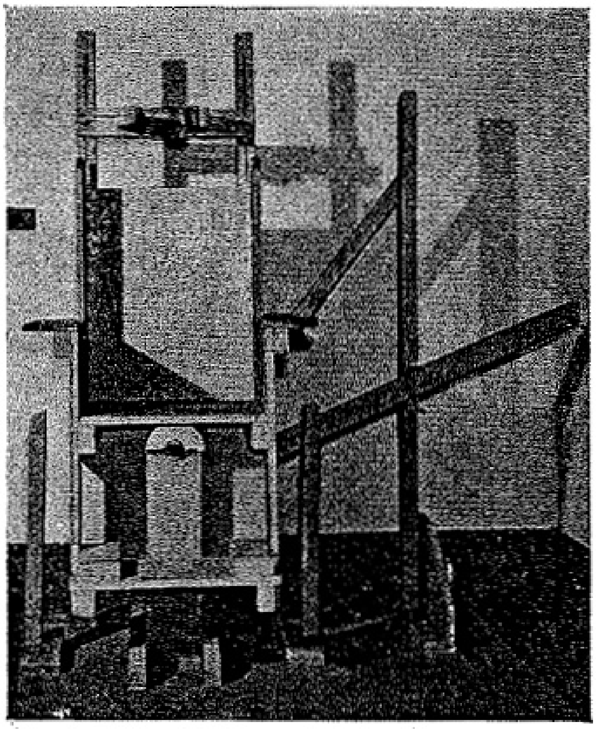

Fig. 5. Tilting chair used in localisation experiments as described in text.

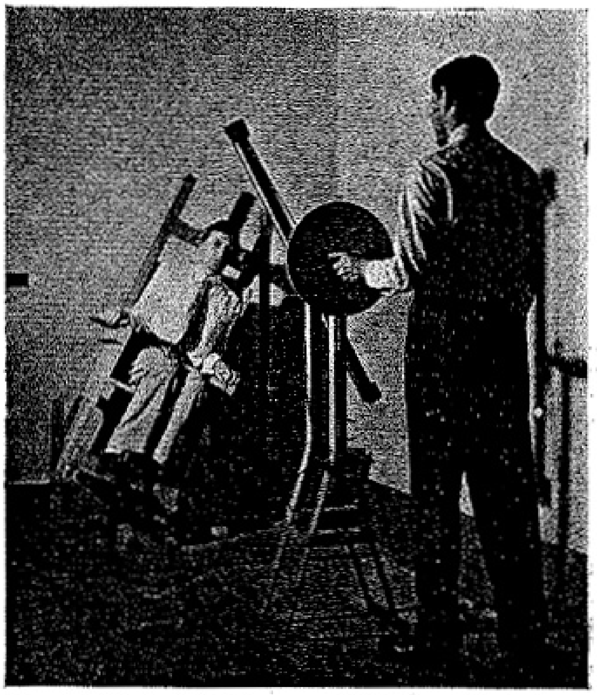

Fig. 6. Chair tilted to one side with subject viewing luminous line. Actual tests were performed in a darkened room.

All made very small errors while erect, and these did not differ significantly from one group to another. However, when setting the luminous line, from a body tilt to their left, men with penetrating injuries of the anterior third of the brain tended to displace the vertical to the right, to a considerably greater extent than normal controls or men with penetrating injuries of the posterior third of the brain. From a body tilt to their right, men with 'frontal' damage tended to displace the line even more to the left than either the other brain-injured adults or the controls. In this respect, the results of this experiment revealed a clearly specific effect—and one of the few, incidentally, we have ever found specific to the frontal lobes (Teuber 1959).

If we interpret displacement of the line opposite the side of tilt as compensation for the tilt of the body, it would seem that damage to the anterior third of the brain leads to an exaggeration of such a compensatory effect. This constant error is a specific effect, but it does not mean that the man with anterior brain lesions is more childlike.

Werner and Wapner (1957) have studied setting of the vertical during body tilt, in children from 6 to 18 years, and found that the younger the child the *smaller* the constant error. That is, there is little or no overcorrection in the young child for the direction of his tilt. Settings of the vertical are about the same regardless of whether he is tilted to the left or to the right. The constant error of displacement grows as the child does, and we must assume that he increasingly compensates for unusual postures.

Auditory Tasks

To explore this phenomenon in another sense modality, Teuber and Liebert (1956) introduced an auditory analogue of the visual setting of the vertical and Liebert and Rudel (1959, Rudel *et al.* 1960) extended this mode of testing to our normal and brain-damaged child subjects. The same chair was used, and while the child was seated upright, or tilted 28° to

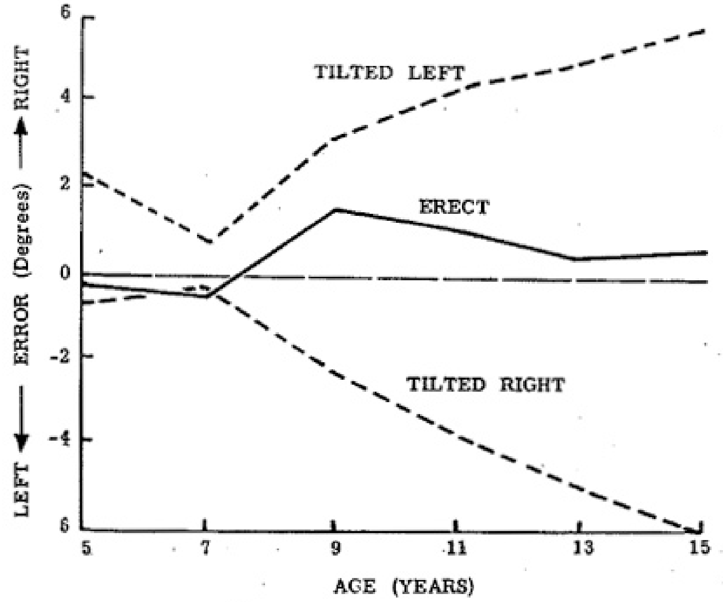

Fig. 7. Auditory localisation by normal children as a function of age and three body positions: erect, 28° to the left, and 28° to the right. Ordinate gives constant errors in degrees of arc.

his left or right, a single earphone emitted clicks once per second above the child's head. The earphone moved in an arc in the subject's coronal plane at a constant distance of 12 inches from the occipital pole. The child was told to say when the click sounded immediately above the midline of his head. The results for audition (see Fig. 7), with normal children, were completely analogous to those reported for vision. The error of displacement of the visual vertical or the auditory midline grows from virtually zero displacement at about 5 years to the displacement normally seen in adults. This is reached by late adolescence (see Liebert and Rudel 1959).

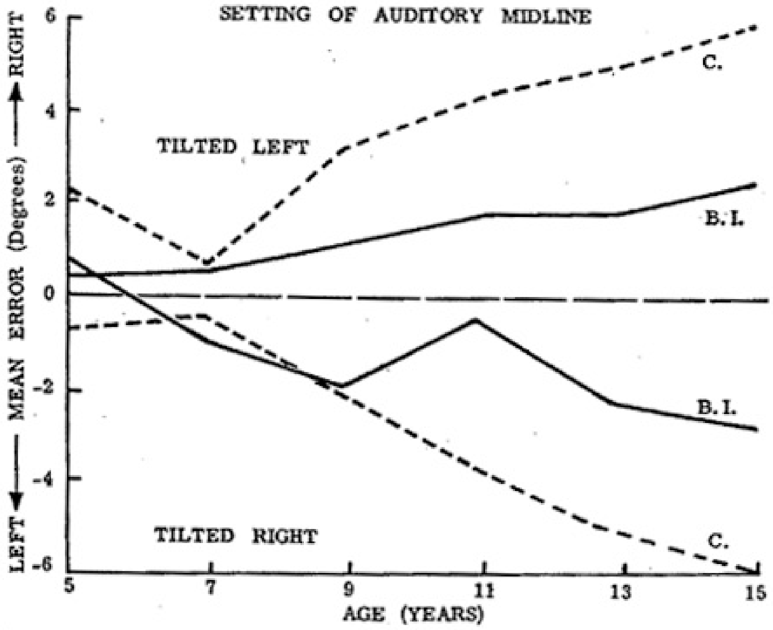

Fig. 8. Auditory localisations by normal and brain-damaged children as a function of age, with body tilted 28° left and 28° right. Dotted lines give results for controls (C); solid lines for brain-injured children (B.I.).

In this sense it might be said that adult brain-injured subjects with frontal damage go beyond the adult norm, while healthy children remain below this norm.

The localisation of the auditory midline during body tilt was then investigated with the same number of brain-damaged children under conditions as comparable as possible (Rudel *et al.* 1960). There were 72 subjects, 36 boys and 36 girls, ranging in age from 4 years 11 months to 18 years. Although all were diagnosed as 'cerebral palsied', their motor impairment ranged from the barely perceptible to severe; some could walk quite normally while others were confined to wheel chairs. There were no late-injury cases among them; all disabilities were considered to be the result of prenatal defect, birth trauma, or encephalopathies acquired early in the first year of life.

The pattern of results (see Fig. 8) is the same for brain-injured and normal children; there is an increasing tendency to displace the sound to the side opposite to their body tilt. This error increases more rapidly and to a greater extent in normal subjects. The constant error of setting the auditory midline during body tilt distinguishes between normal and brain-damaged children *least well* at the lowest ages. A significant divergence does not occur until about the age of 11 years. This difference is maintained through the ages tested, and work now in progress with cerebral palsied adults indicates that there is no further change in this group after the age of 17. Thus, the difference between our brain-damaged and normal children is not one that can be attributed to a temporary lag in the rate of development. The younger children, normal or brain-damaged, do not displace the stimulus very much as a result of body tilt. Yet it was precisely this task which specifically differentiated adults with brain injury in a particular region (frontal) from those with injury elsewhere in the brain. This means that we have here a task which is particularly sensitive to brain injury in the adult—i.e., to brain injury in a focal region of the adult brain—and yet this same task is insensitive to brain damage in children under 11.

Incidentally, in the various groups of brain-damaged children, constant errors of auditory setting were not influenced by any of the other indications of their condition; that is, neither the neurological diagnosis (whether the child was spastic, athetoid or ataxic), nor the severity of impairment, nor the intelligence quotient had any measurable effect on these errors.

Starting-position Effect

The task of adjusting a sound source under conditions of body tilt yields more than specific sign of brain injury in the adult—it also yields nonspecific effects, if the results are differently analysed. Instead of concerning ourselves with the constant error of the setting, we can focus on the so-called starting-position effect (Werner and Wapner 1952).

Whether one uses an auditory or a visual stimulus in this type of localisation experiment, there is the problem of starting the line or the sound source from some point other than the true middle. So as not to prejudice the results in one direction or the other, the stimuli are started from the left and from the right in balanced order, and several trials are given from each direction. If we note the extent to which the subject keeps the line or the sound to the side from which it was started at the beginning of each trial, we can calculate the starting-position effect. This error is independent of sign; it is actually the distance in degrees from the midline when the stimulus is started at the left, plus the distance from the midline when the stimulus is started at the right.

Such an analysis of the responses of our adult brain-injured subjects and their controls showed that *all* adult brain-injured subjects, regardless of classification by locus of injury, had larger starting position errors than normal controls (Teuber and Liebert 1958). For starting-position effects, at least, brain injury does appear to make adult subjects more like normal children. Whether children are setting a visual stimulus to the vertical (Wapner and Werner 1957) or localising a sound source overhead (Liebert and Rudel 1959), they have larger starting-position effects than adults, with the largest starting-position effect in the youngest children. The effect diminishes to about half by late adolescence.

Brain-damaged children do even worse (Rudel *et al.* 1960). Fig. 9 compares normal and brain-damaged children (the same group of 72 with cerebral palsy) on this starting-position effect. At every age level, normal children make a smaller starting-position error than do brain-damaged children. Unlike the constant error of setting the auditory midline, differences in starting-position error between normal and brain-damaged children exist even at the earliest age tested—5 to 7 years. Possibly, normal children under 5 years would respond with as much starting-position effect as these brain-damaged children.

Intelligence, as measured by standard intelligence tests, does not appear to

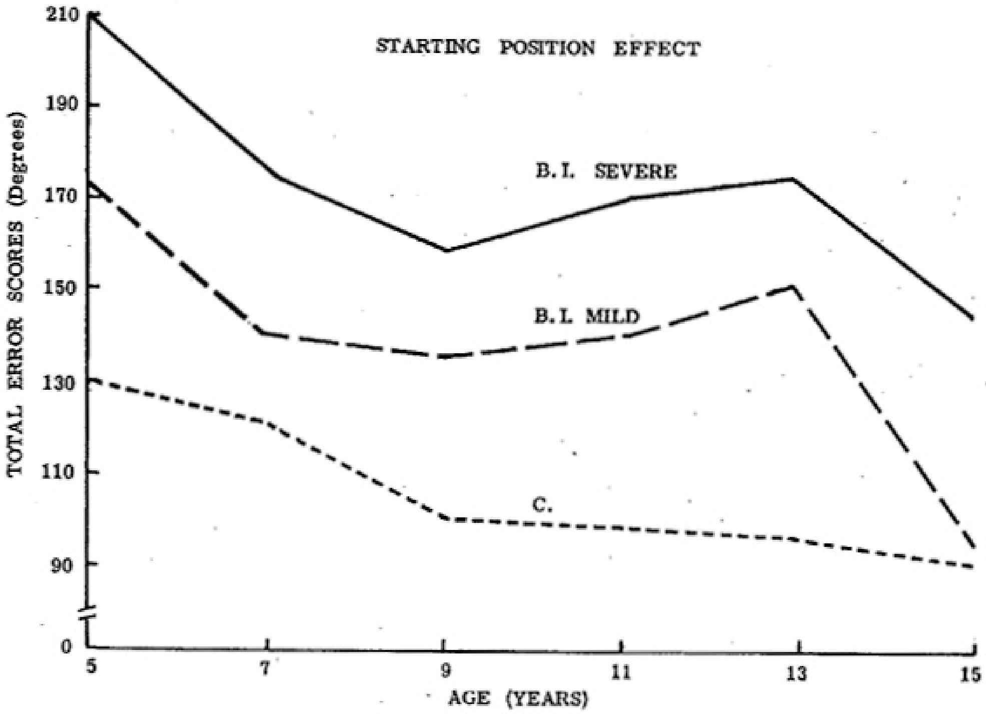

Fig. 9. Starting-position effects in the auditory localisation experiments as a function of age in normal children (C) and in brain-damaged children with mild motor impairment (B.I. mild) and with severe motor impairment (B.I. severe).

distinguish between brain-damaged children with small or large starting-position errors, nor does the neurological diagnosis, whether spastic, athetoid or ataxic. However, brain-damaged children classified as severely impaired (according to their general neurological status) made significantly larger starting-position errors than those classified as mildly impaired, and these in turn had significantly larger starting-position errors than the normal subjects.

Thus, the starting-position effect, like the hidden-figures test, brings out general effects of brain injury, since it does not differentiate among adult brain-injured subjects grouped according to the locus of the injuries. All brain-injured adults appear to do equally badly when compared with normal adults. As on the hidden-figures test, all brain-damaged children, at all age levels, differ from normal controls, and this deficit in performance does not appear to depend on the intelligence level or neurological classification of the children. The analogy with the hidden-figures test is thus complete, for severely impaired brain-damaged children do even worse in terms of starting-position error than mildly impaired children. These, in turn, do worse than normal controls, and this was also the case with the hidden-figures test. For these tasks which appear to be nonspecific indicators of brain damage in the adult, one is tempted to see the forebrain as 'equipotential', to borrow Lashley's term (1929). In the child and in the adult, it may be the size rather than the site of the lesion that is the crucial variable in determining the extent of the deficit on these particular tasks.

Thus far we have considered two types of effect: first, a specific effect, namely, the constant error of setting an auditory midline which specifically points to alterations of performance with injury to the frontal areas in adults; second, a nonspecific phenomenon, the starting-position effect,