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Changes in Brain Function after Manipulation of the Cervical Spine

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ABSTRACT

Objective: To ascertain whether manipulation of the cervical spine is associated with changes in brain function.

Design: Physiological cortical maps were used as an integer of brain activity before and after manipulation of the cervical spine in a large (500 subjects), double-blind controlled study.

Setting: Institutional clinic Participants: Adult volunteers

Intervention: Five hundred subjects were divided into six comparative groups and underwent specific manipulation of the second cervical motion segment. Blinded examiners obtained reproducible pre- and postmanipulative cortical maps, which were subjected to statistical analysis.

Main Outcome Measures: Brain activity was demonstrated by reproducible circumferential measurements of cortical hemispheric blind-spot maps before and after manipulation of the second cervical motion segment. Twelve null hypotheses were developed. The critical alpha level was adjusted in accordance with Bonferroni's theorem to .004 (.05 divided by 12) to reduce the likelihood of wrongly rejecting the null hypothesis (i.e., committing a Type I error).

Results: Manipulation of the cervical spine on the side of an enlarged cortical map is associated with increased contralateral cortical activity with strong statistical significance ($p < .001$). Manipulation of the cervical spine on the side opposite an enlarged cortical map is associated with decreased cortical activity with strong statistical significance ($p < .001$). Manipulation of the cervical spine was specific for changes in only one cortical hemisphere with strong statistical significance ($p < .001$).

Conclusions: Accurate reproducible maps of cortical responses can be used to measure the neurological consequences of spinal joint manipulation. Cervical manipulation activates specific neurological pathways. Manipulation of the cervical spine may be associated with an increase or a decrease in brain function depending upon the side of the manipulation and the cortical hemisphericity of a patient. (J Manipulative Physiol Ther 1997; 20:529–45).

Key Indexing Terms: Cervical Spine; Chiropractic Manipulation; Thalamus; Brain

INTRODUCTION

Manipulation of the cervical spine is a common treatment modality used by many health care practitioners, especially chiropractors, in a variety of applications. The central neurological consequences of cervical manipulation, if any, are not adequately demonstrated in the literature. There has not been a suggestion or demonstration of a validated human model or instrument that can specifically measure the central effects of a cervical spine manipulation. This research is intended to answer questions and promote insights into the central effects of cervical manipulation with specific attention to physiological consequences of human brain activity after a spinal manipulation. This research is also concentrated on the development of a reproducible instrument for the recording of brain activity that is sensitive enough to reflect the consequences of a spinal manipulation. Such an instrument could be used to compare a variety of manipulative techniques and other interventions that might be postulated to have central effects on the human nervous system. Methodology that will allow quantitative evaluation of a neurological response to a manipulation will promote applications to health care and provide a vehicle to identify iatrogenesis from or benefits of a specific mode of therapy. Brain activity change as a consequence of a spinal manipulative procedure will also enable and promote methodology to understand the mechanisms of manipulation and answer questions regarding human neurophysiology. The central effects of manipulative procedures must be known to afford practitioners of the modality better direction in application and in contraindication, which will promote and encourage professional and societal change.

METHODS

Sample and Population

This research used a large group of adult volunteers (500) as the subjects in this study, which was conducted in accordance with the Helsinki Declaration of 1975. These volunteers are

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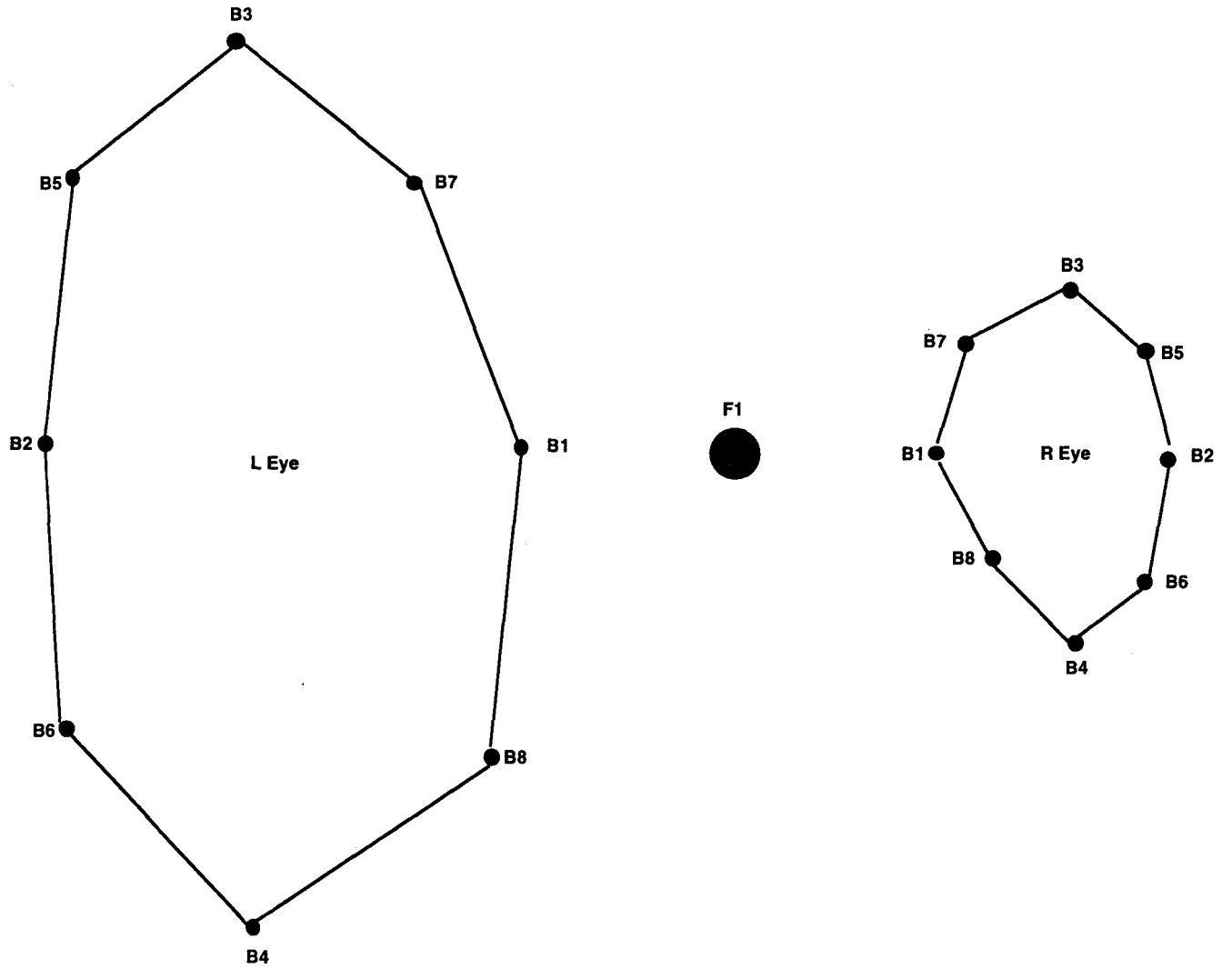


Fig. 1 *Cortical perceptual map demonstrating decreased left cortical hemisphericity*

enrolled in postdoctoral neurology programs at a variety of institutions.

Data Collection

Phase I procedure. Cortical perceptual maps were obtained from adult volunteer subjects after procedures were explained and appropriate releases obtained (Figure 1). Five hundred cortical perceptual maps that were found to be asymmetrical were used in various phases of this study. A chart was placed 28 cm from the forehead of the subject, with a central black dot as a focal target (F1). Subjects were stabilized at 28 cm from F1, which was placed at the same height as the patient's eyes, and this relationship was maintained throughout the examination. Subjects were taught to fixate on F1 with one eye while the other eye was patched to prevent binocular vision. Investigators were trained to observe any extraocular movements that would change the visual axis of the subject and terminate the examination if any movement occurred.

The investigator superimposed another target, a red dot on a clear plastic extender (F2), over the central target F1 and moved F2 laterally toward the temporal field of the subject's uncovered eye, which remained fixed on the central target F1. Subjects notified the investigator when F2 could not be perceived and the investigator made a dot (B1) on the chart at that point. The temporal migration of F2 was continued until the subject could again perceive F2 and another dot (B2) was made at that point. The investigator then placed F2 in the center of the two dots B1 and B2 (on the axis of a line that would connect B1 and B2) and moved F2 vertically at 90° to the direction of temporal migration already mapped (90° to the axis of a line that would connect B1 and B2) and made a dot (B3) when the subject could perceive F2 again.

F2 was then moved inferiorly at 90° to the original temporal migration until the subject could perceive F2, and another dot (B4) was made at this point. The investigator then placed F2 in the center of the four dots B1–B4 and moved F2 temporally and superiorly, bisecting the superior and lateral temporal dots B3 and B2, until the subject could perceive F2, and another dot (B5) was made. F2 was then placed in the center of the five dots B1–B5 and moved temporally and inferiorly, bisecting the inferior and lateral temporal field dots B2 and B4 until the

subject could perceive F2, and another dot (B6) was made. F2 was then placed in the center of the six dots B1–B6 and moved nasally and superiorly, bisecting the superior and lateral nasal dots B3 and B1 until the subject could perceive F2, and another dot (B7) was made. F2 was then placed in the center of the seven dots B1–B7 and moved nasally and inferiorly, bisecting the inferior and lateral nasal dots B4 and B1 until the subject could perceive F2, and another dot (B8) was made. The procedure was repeated on the opposite eye with patching of the first eye tested. The eight dots B1–B8 on either side of the focal target F1 were connected and the cortical perceptual maps were mapped by measuring the distances between each dot in centimeters and adding individual distances to describe the circumference of the blind spot. The entire procedure was then repeated by another investigator in a blinded fashion. The two individually obtained cortical perceptual maps were superimposed over a bright light source by a blinded examiner who accepted them as reproducible or rejected them as being different. This procedure was repeated by another blinded investigator and cortical perceptual maps were considered reproducible if accepted as such by both investigators.

Phase 1 results. Four hundred seventy-three maps were found to be reproducible by superimposition over a bright light source. No tests were found to be reproducible by one blinded examiner and not reproducible by another. Twenty-seven subjects had maps that were not reproducible and were eliminated from the next phase of the experiment. This phase demonstrated that manual perimetry mapping is an inexpensive, accurate (94.6%) and reproducible method of recording the physiological blind spot and, thus, cortical activity.

Phase 2 instrumentation. A constant type of environmental stimulation (vision) was used in this research to stimulate the brain through specific known neuronal pathways. The effects of this environmental stimulation were used to affect human perceptual activity and demonstrate the effectiveness of cortical mapping through comparison. Manipulation of the second cervical motion segment was used as a window of comparison of environmental change.

Phase 2 procedure. Twenty individuals who had increased sizes of cortical perceptual maps from the right eye were divided into two groups of 10 (Figure 2). Group 1 was composed of subjects whose second cervical motion segments on the side of the increased cortical perceptual map were identified by investigators skilled in palpation and confirmed by an independent investigator. Group 2 was composed of subjects whose second cervical motion segments on the side opposite of the increased cortical perceptual map were identified by investigators skilled in palpation and confirmed by an independent investigator.

The second cervical motion segment was then reduced on the side of the increased blind spot in group 1 (Figure 3) and on the side opposite of the increased blind spot in group 2 (Figure 4). In group 1 subjects, the second cervical motion segment was manipulated with the investigator's thumb (overlying the right spinous laminae junction) inducing a moment of $+X$ translation and $-\theta Y$ axial torque with contralateral (L) Y axis translation. In the group 2 subjects, the second cervical motion segment was manipulated with the investigator's thumb (overlying the left spinous laminae junction) inducing a moment of $-X$ translation and $+\theta Y$ axial torque with contralateral (R) Y axis translation (Figure 5).

Postmanipulation cortical perceptual maps were made of all individuals in groups 1 and 2 by independent blinded investigators who were not aware of the side of manipulation or the results of previous cortical perceptual mapping.

Phase 2 results. The post manipulation maps for groups 1 and 2 were compared for reproducibility using blinded investigators and bright light superimposition and all were found to be reproducible.

Phase 3 procedure. The next phase of the investigation used the remaining 453 subjects who had differences in the size of their cortical perceptual maps. They were divided into group 3 (310 subjects) and group 4 (143) based upon the side of the largest cortical perceptual map. Group 3 subjects demonstrated enlarged right cortical perceptual maps, whereas group 4 subjects demonstrated enlargement of the left cortical perceptual maps. A decrease in cortical perceptual map size was associated with manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map in groups 1 and 2; therefore, palpation and identification of motion segments on the side of the enlarged cortical perceptual map was accomplished in both groups 3 and 4. The second cervical motion segment on the side of the increased right cortical perceptual map was identified by investigators skilled in palpation and confirmed by an independent examiner in all group 3 subjects. The second cervical motion segment on the side of the increased left cortical perceptual map was identified by investigators skilled in palpation and confirmed by an independent examiner in all group 4 subjects.

The second cervical motion segment was manipulated on the right side in group 3 and the left side in group 4. In group 3 subjects, manipulation of the second cervical motion segment was by the investigator's right thumb (overlying the right spinous laminae junction) inducing a moment of $+X$ translation and $-\theta Y$ axial torque with contralateral (L) Y axis translation. In the group 4 subjects, manipulation of the second cervical motion segment was by the investigator's left thumb (overlying the left spinous laminae junction) inducing a moment of $-X$ translation and $+\theta Y$ axial torque with contralateral (R) Y axis translation.

Postmanipulation cortical perceptual maps were made of all individuals in groups 3 and 4 by two independent blinded investigators who were unaware of the side of manipulation or the results of previous cortical perceptual mapping. These postmanipulation maps were compared for reproducibility using bright-light superimposition.

Phase 3 results. Four hundred thirty-nine maps (96.9%) were found to be reproducible [300 in group 3 (96.7%) and 139 in group 4 (97.2%)] and 14 were not. The 14 maps that were not reproducible were removed from the study. New groups 5 and 6 were made to compare the sizes of the maps before and after treatment. Group 5 was composed of the 300 cortical percep-

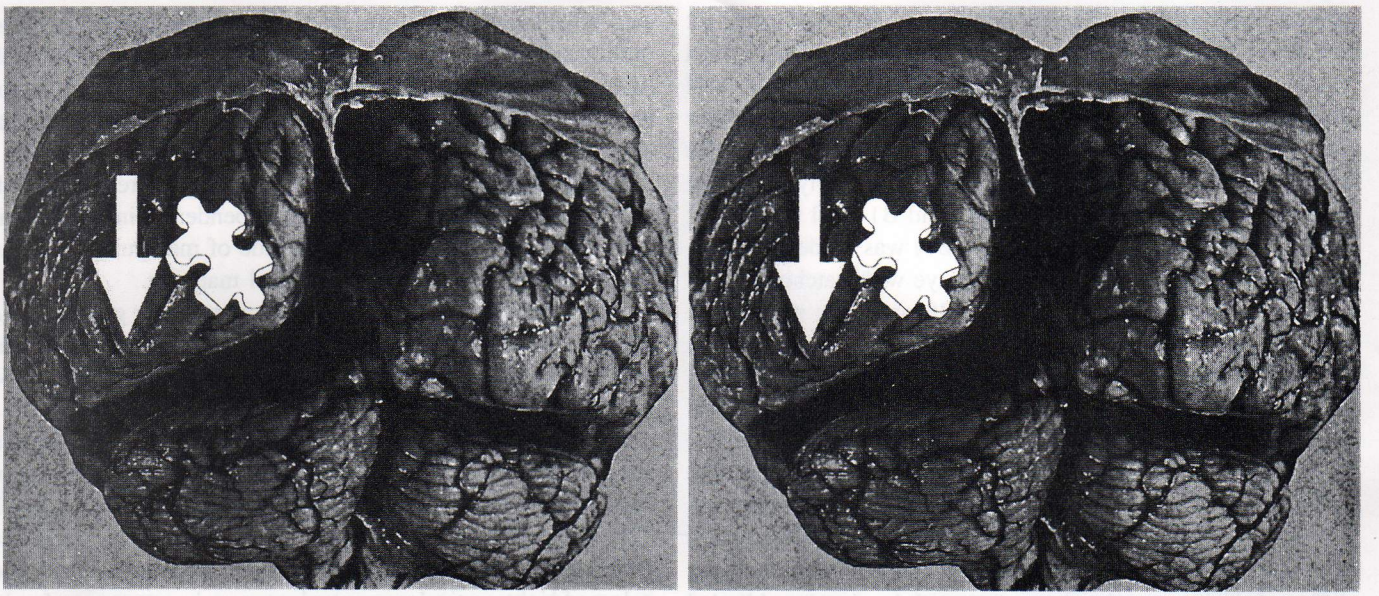


Fig. 2 *Two groups with decreased left cortical hemisphericity.*

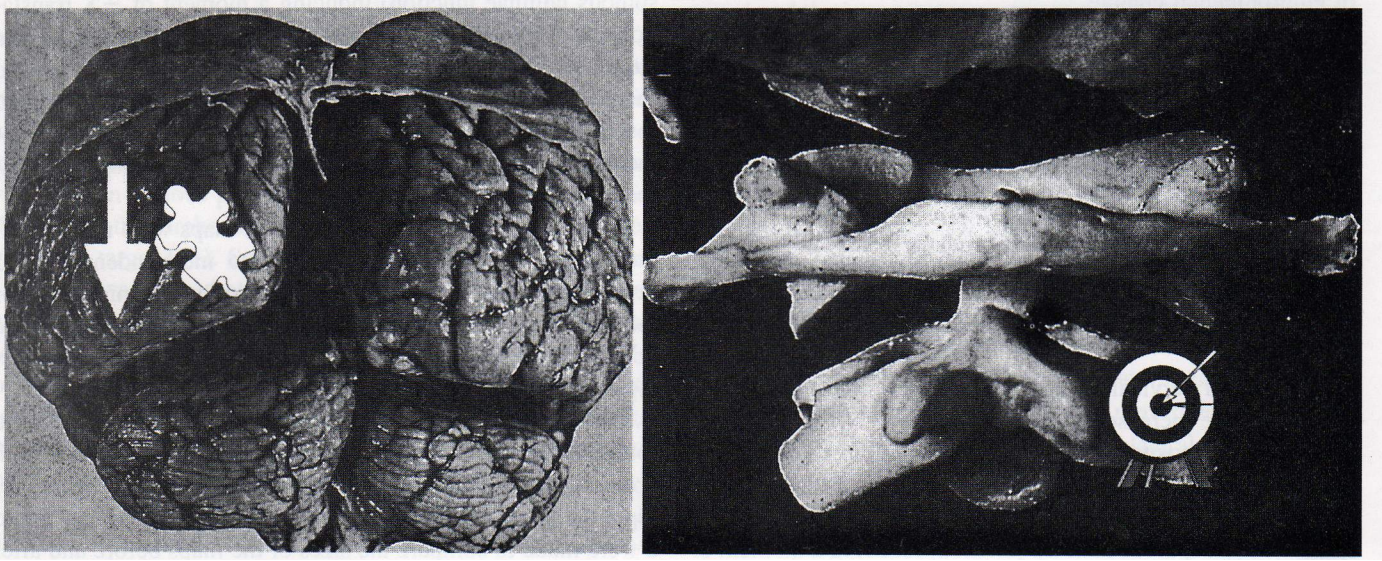
tual maps that were enlarged on the right side before treatment and their post-treatment maps that were found to be reproducible. Group 6 was composed of the 139 cortical perceptual maps that were enlarged on the left side before treatment and their post-treatment maps that were found to be reproducible.

RESULTS

All of the subjects (10) in group 1 demonstrated reduction in the size of the right cortical perceptual map (Figure 6), whereas all of the subjects (10) in group 2 demonstrated enlargement of the right cortical perceptual map (Figure 7). Twelve null hypotheses were developed. A series of matched pairs and independent groups t tests were conducted to test the null hypotheses. The desired critical alpha level was .05. However, because multiple related tests were being performed, the critical alpha level was adjusted in accordance with Bonferroni's theorem to .004 (.05 divided by 12). This adjustment was made to reduce the likelihood of wrongly rejecting the null hypothesis (i.e., committing a Type I error).

Below, each null hypothesis is presented, together with a discussion and tabular presentation of the findings for each hypothesis.

Null hypothesis 1. For subjects in group 1 whose second cervical motion segment was manipulated on the side of the increased right cortical perceptual map, there is no significant difference between the pretest and post-test cortical perceptual maps for the left eye. A matched-pairs t test was performed to compare pretest and post-test left-eye cortical perceptual maps



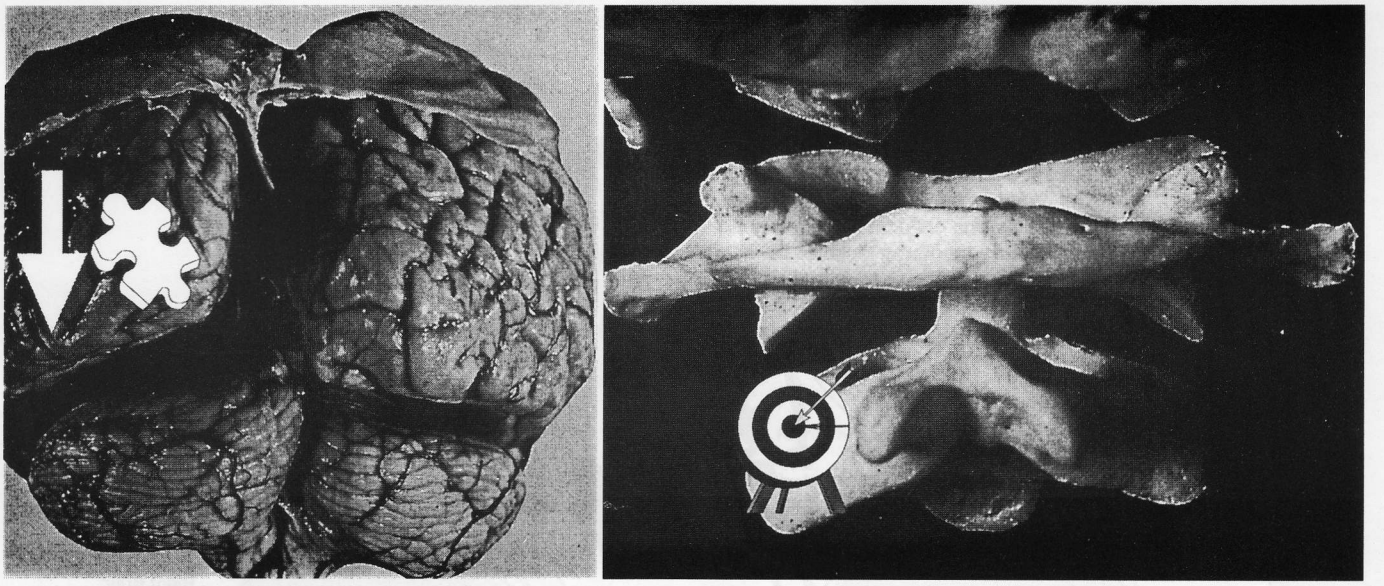


Fig. 4 *Manipulation on side of decreased cortical hemisphericity.*

for group 1. Table 1 shows that we fail to reject the null hypothesis. The pretest and post-test means were nearly identical and the t statistic was not significant.

Null hypothesis 2. For subjects in group 1 whose second cervical motion was manipulated on the side of the increased right cortical perceptual map, there is no significant difference between the pretest and post-test cortical perceptual maps for the right eye. A matched-pairs t test was performed to compare pretest and post-test right eye cortical perceptual maps for group 1. Table 2 shows that we reject the null hypothesis and conclude that there was strong significant difference between pretest and post-test cortical perceptual maps $t\ (9) = 5.36, p < .001$, and that the reduction in the size of the cortical perceptual map associated with the environmental procedure in group 1 was significant.

Null hypothesis 3. For subjects in group 2 whose second cervical motion segment was manipulated on the side opposite the increased right cortical perceptual map, there is no significant difference between the pretest and post-test cortical perceptual maps for the left eye. A matched-pairs t test was performed to compare pretest and post-test left eye cortical perceptual maps for group 2. Table 3 shows that we fail to reject the null hypothesis. The pretest and post-test means were similar and the t-statistic was not significant.

Null hypothesis 4. For subjects in group 2 whose second cervical motion segment was manipulated on the side opposite the

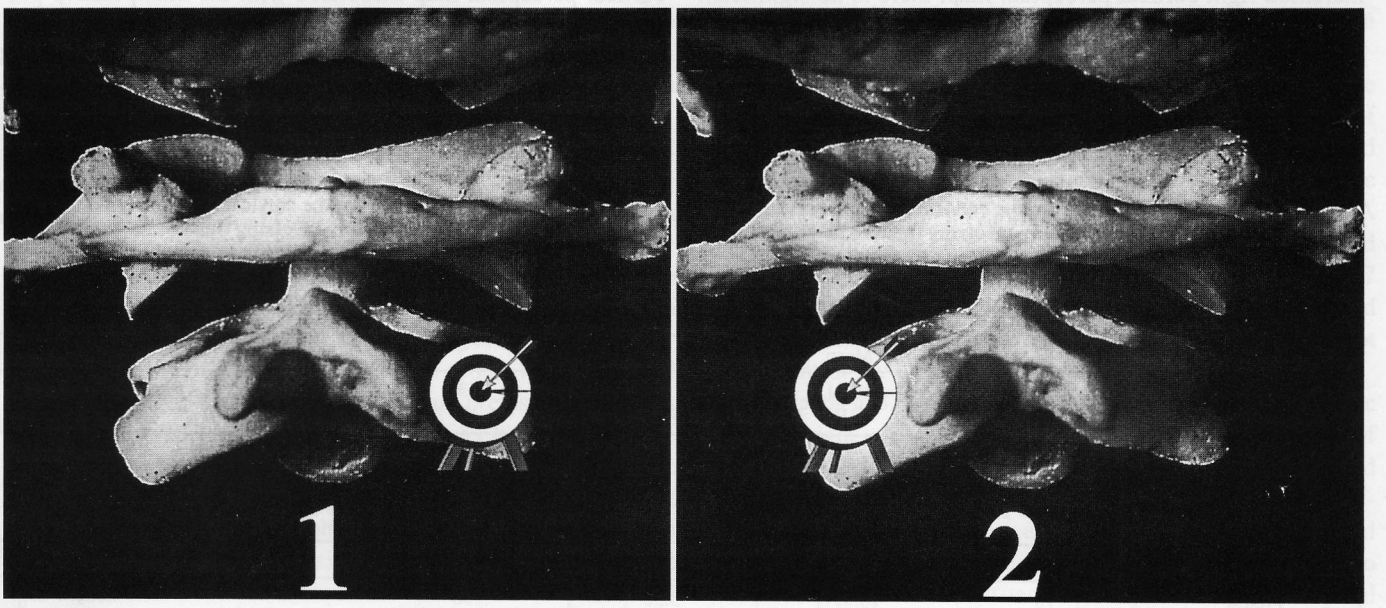


Fig. 5 *Group 1 manipulation right side-group 2 manipulation left side.*

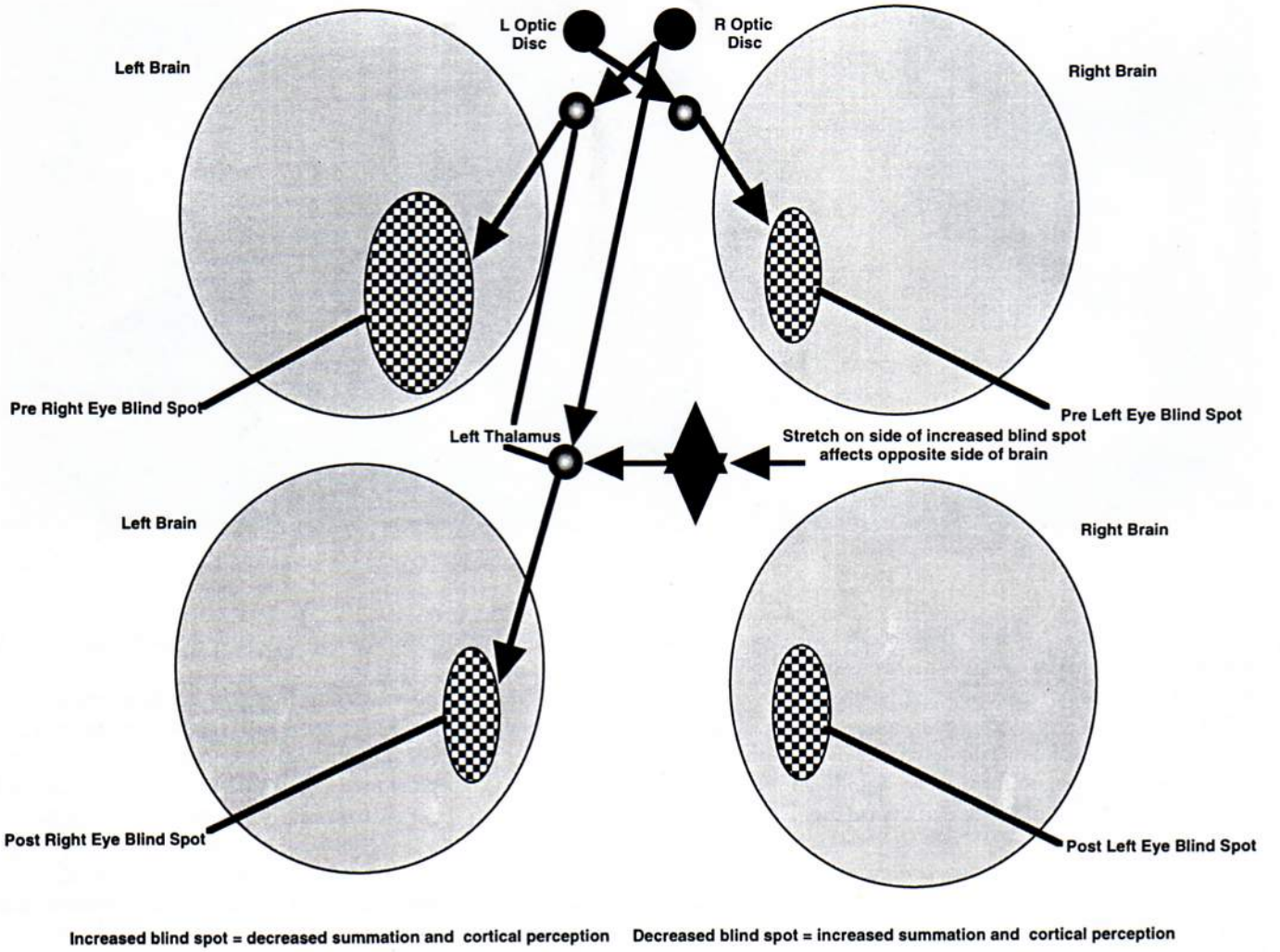


Fig. 6 *Manipulation on side opposite decreased hemisphericity.*

increased right cortical perceptual map, there is no significant difference between the pretest and post-test cortical perceptual maps for the right eye. A matched-pairs *t* test was performed to compare pretest and post-test right eye cortical perceptual maps for group 2. Table 4 shows that we reject the null hypothesis and conclude that there was strong significant difference between pretest and post-test cortical perceptual maps, $t\ (9) = 5.46$, $p < .001$, and that the increase in the size of the cortical perceptual map associated with the manipulative procedure in group 2 was significant.

Null hypothesis 5. When comparing subjects whose second cervical motion segment was manipulated on the side of the increased right cortical perceptual map (group 1) with subjects whose second cervical motion segment was manipulated on the side opposite the increased right cortical perceptual map (group 2), there is no significant difference in the amount of change in

Table 1. *Comparison of pretest and post-test left-eye cortical perceptual maps for group 1*

	n	Mean	SD	*t*	*df*	*p*
Pretest	10	10.01	0.58	.31	9	.763
Post-test	10	10.04	0.75			

Table 2. *Comparison of pretest and post-test right-eye cortical perceptual maps for group 1*

	n	Mean	SD	*t*	*df*	*p*
Pretest	10	16.39	3.58	5.36	9	<.001
Post-test	10	10.40	0.77			

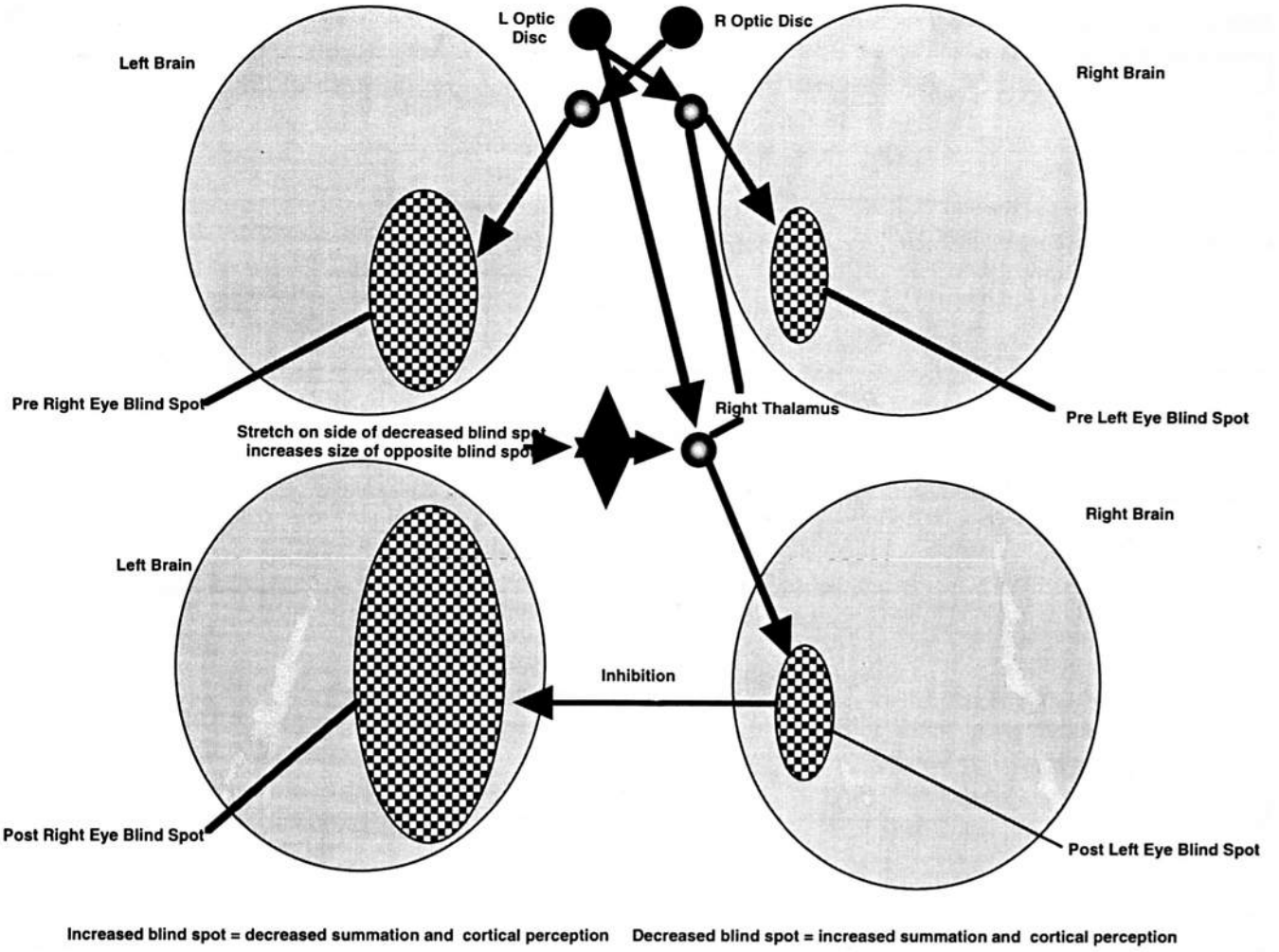


Fig. 7 *Manipulation on side of decreased hemisphericity.*

the cortical perceptual maps for the left eye. An independent-groups t test was performed to compare group 1 with group 2 on the degree of change (post-test minus pretest) in the left eye cortical perceptual maps. Table 5 shows that we fail to reject the null hypothesis and conclude that the difference between the two groups was not significant.

Null hypothesis 6. When comparing subjects whose second cervical motion segment was manipulated on the side of the increased right cortical perceptual map (group 1) with subjects whose second cervical motion segment was manipulated on the side opposite the increased right cortical perceptual map (group 2), there is no significant difference in the amount of change in the cortical perceptual maps for the right eye. An independent-groups t test was performed to compare group 1 with group 2 on the degree of change (post-test minus pretest) in the right eye cortical perceptual maps. Table 6 shows that we reject the null hypothesis and conclude that the difference between the two groups was significant, $t\ (18) = 7.49$, $p < .001$, and that the changes in the size of the right cortical perceptual map associated with the manipulative procedures in groups 1 and 2 was significant with decreases in the size of cortical perceptual maps associated with manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map and increases in the size of cortical perceptual maps associated with manipulation of the second cervical motion segment on the side opposite the enlarged cortical perceptual map.

Null hypothesis 7. For subjects who demonstrated reproducible enlarged right cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged map (group 5), there is no significant difference between the pretest and post-test cortical perceptual maps for the left eye. A matched-pairs t test was performed to compare pretest and post-test left-eye cortical perceptual maps for group 5. Table 7 shows that we fail to reject the null hypothesis. The pretest and post-test means were nearly identical and the t-statistic was not significant at the critical alpha level of .004.

Null hypothesis 8. For subjects who demonstrated reproducible enlarged right cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 5), there is no significant difference between the pretest and post-test cortical perceptual maps for the right eye. A matched-pairs t test was performed to compare pretest and post-test right-eye cortical perceptual maps for group 5. Table 8 shows that we reject the null

Table 3. *Comparison of pretest and post-test left-eye cortical perceptual maps for group 2*

	n	Mean	SD	*t*	*df*	*p*
Pretest	10	14.43	4.99	1.10	9	.301
Post-test	10	15.52	5.62			

Table 4. *Comparison of pretest and post-test right-eye cortical perceptual maps for group 2*

	n	Mean	SD	*t*	*df*	*p*
Pretest	10	22.03	6.77	5.46	9	<.001
Post-test	10	26.07	6.87			

Table 5. *Comparison of group 1 with group 2 on the post-test minus pretest change in the left-eye cortical perceptual maps*

	n	Mean	SD	*t*	*df*	*p*
Group 1	10	0.03	0.31	1.06	9	.302
Group 2	10	1.09	3.14			

Table 6. *Comparison of group 1 with group 2 on the post-test minus pretest change in the right-eye cortical perceptual maps*

	n	Mean	SD	*t*	*df*	*p*
Group 1	10	−5.99	3.53	7.49	9	<.001
Group 2	10	4.04	2.34			

Table 7. *Comparison of pretest and post-test left-eye cortical perceptual maps for group 5*

	n	Mean	SD	*t*	*df*	*p*
Pretest	300	12.90	4.22	2.27	299	.24
Post-test	300	12.83	4.11			

Table 8. *Comparison of pretest and post-test right-eye cortical perceptual maps for group 5*

	n	Mean	SD	*t*	*df*	*p*
Pretest	300	21.08	7.38	18.25	299	<.001
Post-test	300	10.40	0.77			

Table 9. *Comparison of pretest and post-test left-eye cortical perceptual maps for group 6*

	n	Mean	SD	*t*	*df*	*p*
Pretest	139	19.22	6.70	11.56	138	<.001
Post-test	139	13.75	5.20			

Table 10. *Comparison of pretest and post-test right-eye blind spot maps for group 6*

	n	Mean	SD	*t*	*df*	*p*
Pretest	139	12.67	9.00	.94	138	.349
Post-test	139	11.99	3.23			

Table 11. *Comparison of group 5 with group 6 on the post-test minus pretest change in the left-eye cortical perceptual maps*

	n	Mean	SD	*t*	*df*	*p*
Group 5	300	−0.08	0.58	16.58	437	<.001
Group 6	139	−5.47	5.57			

Table 12. *Comparison of group 5 with group 6 on the post-test minus pretest change in the right-eye cortical perceptual maps*

	n	Mean	SD	*t*	*df*	*p*
Group 5	300	−5.88	5.58	7.63	437	<.001
Group 6	139	−0.68	8.52			

hypothesis and conclude that there was strong significant difference between pretest and post-test cortical perceptual maps, $t\,(299) = 18.25$, $p < .001$, with a marked reduction in the size of the enlarged cortical perceptual map occurring after manipulation of the second cervical motion segment on the side of the enlarged blind spot.

Null hypothesis 9. For subjects who demonstrated reproducible enlarged left cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 6), there is no significant difference between the pretest and post-test cortical perceptual maps for the left eye. A matched-pairs *t* test was performed to compare pretest and post-test left-eye cortical perceptual maps for group 6. Table 9 shows that we reject the null hypothesis, and conclude that there was a strong significant reduction in the left-eye cortical perceptual maps, $t\,(138) = 11.56$, $p < .001$, with a marked reduction in the size of the enlarged cortical perceptual map occurring after manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map.

Null hypothesis 10. For subjects who demonstrated reproducible enlarged left cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 6), there is no significant difference between the pretest and post-test cortical perceptual maps for the right eye. A matched pairs *t* test was performed to compare pretest and post-test right- eye cortical perceptual maps for group 6. Table 10 shows that we fail to reject the null hypothesis and conclude that the difference was not significant.

Null hypothesis 11. When comparing subjects who demonstrated reproducible enlarged right cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 5) with subjects who demonstrated reproducible enlarged left cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 6), there is no significant difference in the amount of change in the cortical perceptual maps for the left eye. An independent-groups *t* test was performed to compare group 5 with group 6 on the degree of change (post-test minus pretest) in the left-eye cortical perceptual maps. Table 11 shows that we reject the null hypothesis and conclude that the difference between the two groups was significant, $t\,(437) = 16.58$, $p < .001$.

Null hypothesis 12. When comparing subjects who demonstrated reproducible enlarged right cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 5) with subjects who demonstrated reproducible enlarged left cortical perceptual maps before manipulation of the second cervical motion segment on the side of the enlarged cortical perceptual map (group 6), there is no significant difference in the amount of change in the cortical perceptual maps for the right eye. An independent-groups *t* test was performed to compare group 5 with group 6 on the degree of change (post-test minus pretest) in the right-eye cortical perceptual maps. Table 12 shows that we reject the null hypothesis and conclude that the difference between the two groups was significant, $t\,(437) = 7.63$, $p < .001$.

DISCUSSION

The optic disk is not sensitive to light; every eye is blind in a small portion of its visual field (Figure 8). Individuals cannot perceive that they are actually blind in a field of vision because of perceptual completion and filling in of the physiological blind spot, which varies in cortical receptive field size in different individuals (1, 2). Ocular dominance stripes are present throughout most of the visual striate cortex as long, parallel or bifurcating bands alternately dominated by the ipsilateral or contralateral eye and are absent from the cortical representations of the blind spot and the monocular crescent (3). The cortical representation of the region of the visual field that corresponds to the contralateral eye's blind spot is not strictly monocular, as previously thought, and the absence of direct retinal afferents from one eye to this region of cortex suggests the involvement of horizontal cortical connections (4). The frequency of firing of these cortical connections affects visual perception and enlargement of the blind spot might be attributable to any mechanism that decreases the firing rate of horizontal cortical connections, hence decreasing the probability of neuronal summation.

Enlargement of the blind spot occurs in many syndromes, including the multiple evanescent white-dot syndrome, acute macular neuroretinopathy, acute idiopathic blind-spot enlarge-

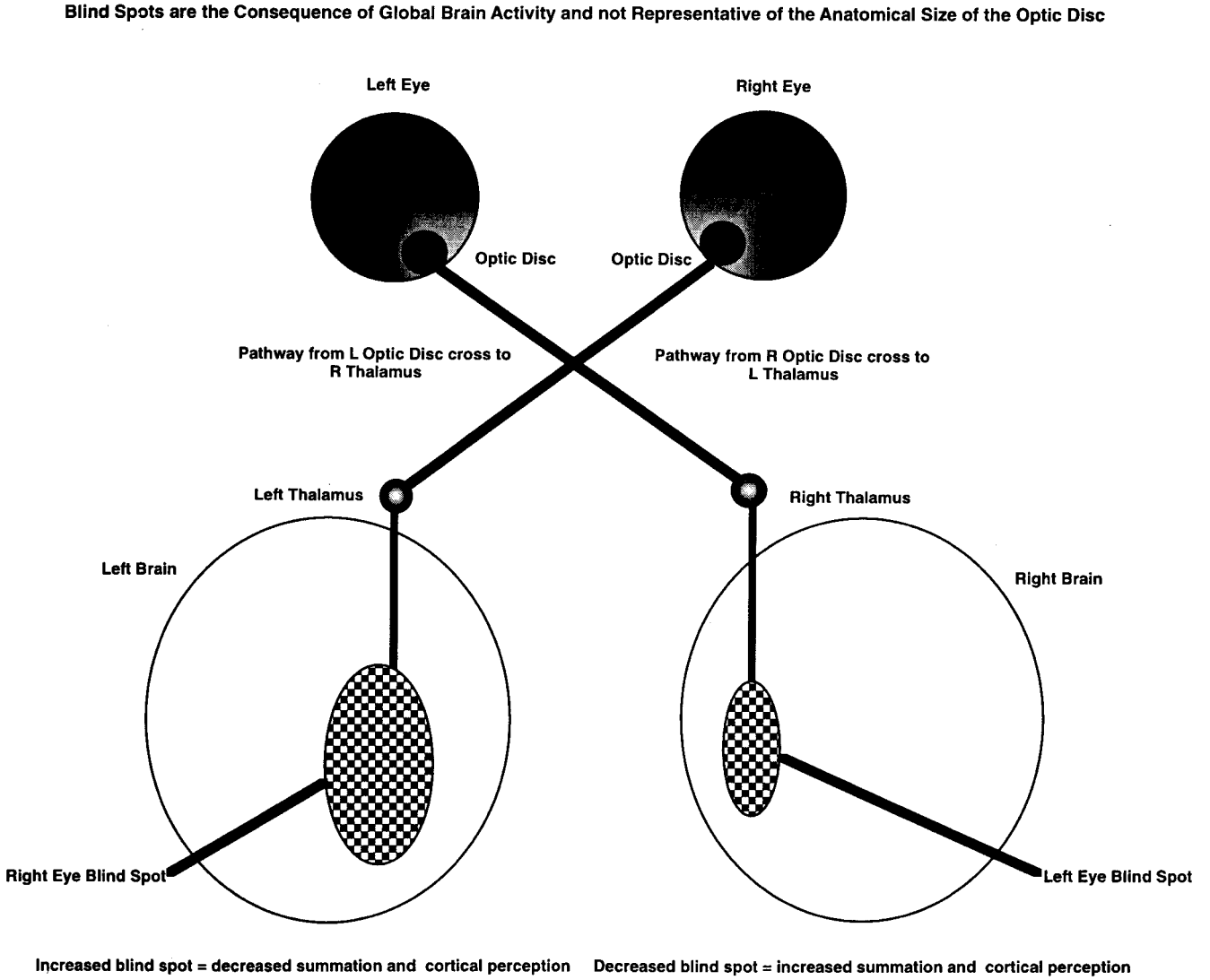


Fig. 8 *Physiology of blind spot and cortical integration.*

ment syndrome and multifocal choroiditis or pseudo presumed ocular histoplasmosis, which demonstrate an overlap in clinical findings and a probable common link in their etiology (5). The big-blind-spot syndrome is often associated with systemic vascular disease; in the majority of cases, it occurs in an otherwise healthy patient with no known systemic disease or ocular problem, with no conclusive evidence existing that any treatment alters its natural history (6). Acute idiopathic blind-spot enlargement has also been attributed to peripapillary retinal dysfunction (7). Enlargement of the blind spot and prolonged latency of the P100 component with decreased amplitude in pattern-reversal visual evoked cortical potentials have been described in a case of multiple evanescent white-dot syndrome (8). Other investigators have observed that blind spot enlargement and depigmentations of the retinal pigment epithelium may remain as defects after multiple evanescent white-dot syndrome (9).

Many patients have had an enlargement of the blind spot with a widespread visual field loss that is not explained by fundus changes; the causal relationship between the initiating event and the widespread functional loss remains unknown (10). Acute idiopathic blind-spot-enlargement syndrome patients have also had extensive unrewarding medical and neurological investigations because of suspected diagnoses, including central nervous system disorders, cancer-associated retinopathy, retinal vasculitis, diffuse unilateral subacute neuroretinitis and tapetoretinal degenerations with no cause of their disorder determined and no effective treatment found (11). The superimposition of the blind spot in the visual field onto the optic disc on a retinal photograph has demonstrated that some visual field scotomata cannot be related to any visible funduscopic or angiographical morphology (12), yet the patient is unable to perceive vision in the target area.

There have been a variety of epidemiologic investigations of blind spots, including observations of the effect of microwaves, which result in altered sizes of the blind spot (13). As well as diagnostic inventories, treatments of visual conditions can also be monitored by blind-spot changes, including the observation that there is a decrease of the blind spot with improvement of primary glaucoma (14). Early visual-field signs in glaucoma

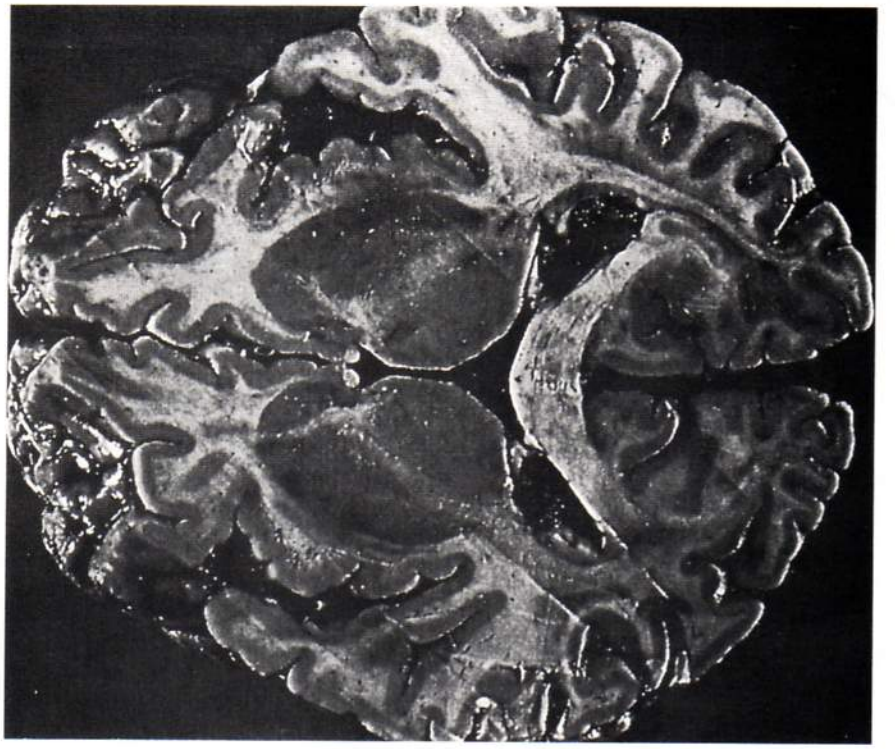


Fig. 9 *Cerebral cortex integration.*

have also been associated with pericecal scotoma in evolution around the blind spot (15). Multiple events affecting vision are often related, which suggests that coexisting factors can confound and obscure accurate diagnoses and that careful patient clinical and laboratory investigations are frequently necessary for correct diagnosis (16). It is clear that the size and shape of the blind spot is a product of neuronal activity and that this activity can be affected by a variety of processes. It was therefore chosen as a sensitive integer of brain activity that could be used to measure changes in cortical activity if other integers were manipulated. There are many methods of recording blind spots. For instance, automated static perimetry commonly reveals glaucomatous defects temporal to the blind spot, but usually adds significant information over central testing only in patients with late visual-field changes (17). Physicians who apply computerized static perimetry should know about the spatial characterization of the individual examination programs of the physiological size and of the possible variations of the blind spot and they should evaluate the correlation of all the quantities (18). Different methodology can be used to ease correlation. CAMEC allowed better detection and quantification of blind spots in patients > 4 yr of age than the Dicon Auto-Perimeter (19). Blind-spot detection using a multifixation campimeter has been demonstrated to vary greatly when patients have clustering fixation targets corresponding to the physiological blind spot (20). Express saccades are not unique to experimental situations in which only a single stimulus appears on an otherwise homogeneous surface; they can be generated readily, as long as the target stimulus is made visible by virtue of luminance, chrominance, motion or a combination of more than one surface medium and as long as the target does not appear concurrently with a salient group of other nontarget stimuli (21). Interestingly, the largest intersubject variability of electroretinography responses to local luminance modulation is found in the fovea, with some nasal-temporal asymmetry observed in all subjects and higher response densities in the temporal field outside the blind spot (22).

Of all the methods of testing available, there is also inexpensive testing available, as demonstrated with the findings that a nontransmitting channel on a 21-inch home television screen can demonstrate blind spots on individuals who had never perceived their field defects (23). Blind spot measurement is useful in many applications and it is ideal to use a methodology of measurement and quantification that is accurate, reproducible and inexpensive. The employment of a measurement of the blind spot using a focal target spot and manual perimetry as described in the methodology section of this paper fulfills these needs.

Excitatory and inhibitory mechanisms, active spatially and temporally between the input and the output of thalamic neurons, determine the nature of the information transmitted to the cerebral cortex (24) and changes in the size of the blind spot after manipulation of spinal joints might occur as a consequence of changes in synaptic summation at thalamic neurons. The responses of ventrobasal thalamic neurons to the natural stimulation of somatosensory afferents arising from mechanoreceptors of the rat are mediated by ionotropic excitatory amino acids, such as arginine, which facilitates sensory synaptic transmission via the synthesis of nitric oxide (25). This may represent a novel local positive-feedback modulatory system which could enhance the responsiveness of thalamic neurons to sensory input from a variety of environmental modal-

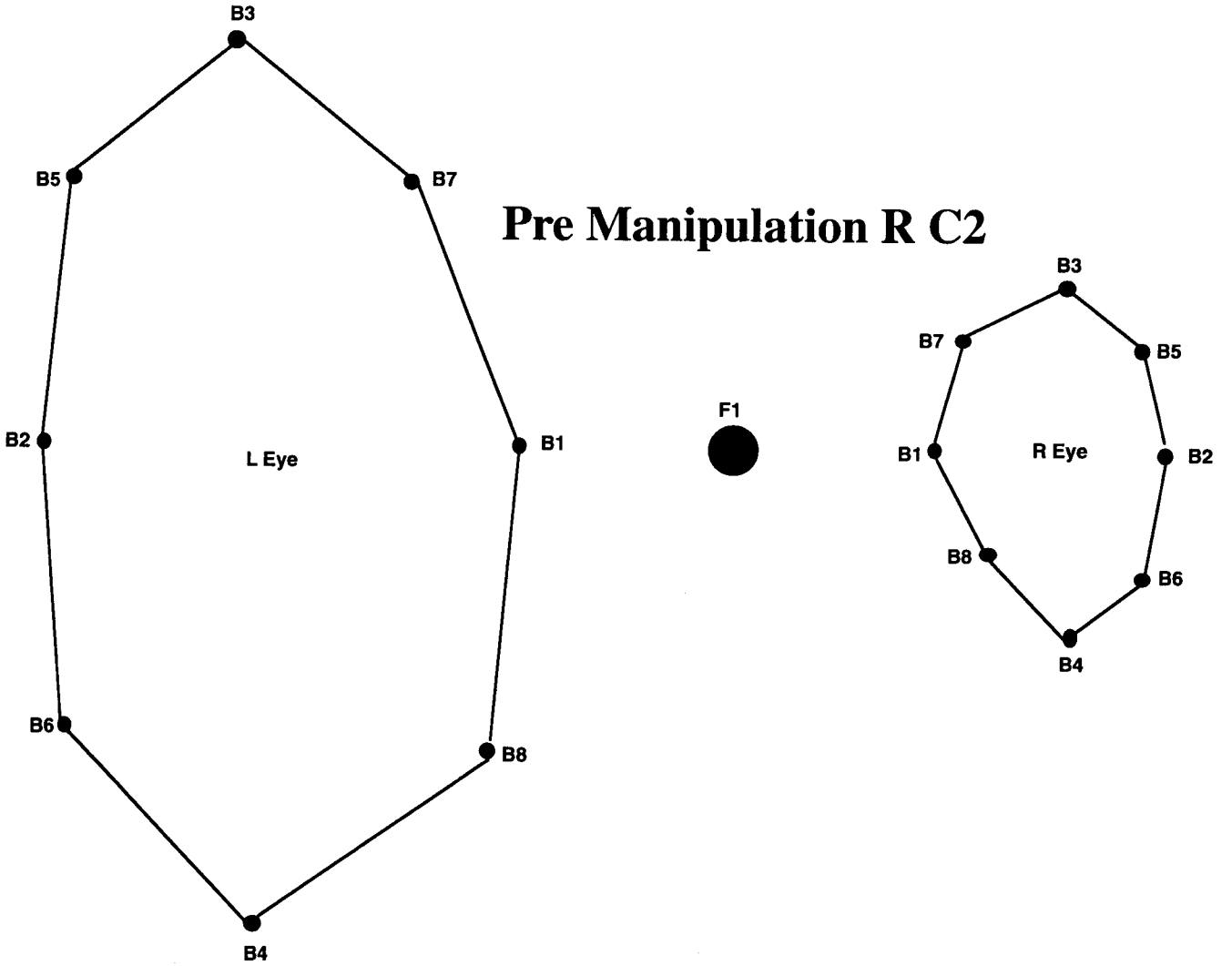


Fig. 10 *Premanipulation right C2.*

ities. The parasol system of the retina, which courses through the magnocellular layers of the lateral geniculate nucleus to cortex, can convey the necessary signals for the generation of visual aftereffects, whereas the central factors that contribute to the visual aftereffects occur either in the striate cortex or are conveyed to higher centers through regions other than the striate cortex or middle temporal regions (26), which suggests an integration of neurophysiological variables.

The amplitude of somatosensory receptor potentials will influence the frequency of firing of cerebello-thalamocortical loops that have been shown to maintain a central integrative state of cortex (27). Changes in the amplitude of muscle stretch receptors and joint mechanoreceptors that dictate the frequency of firing of primary afferents that contribute to cerebello-thalamocortical loops should also affect the integrative cortical state, which might affect the size of the blind spot when visual afferents are maintained in a steady state. Vision is dependent on ordered neuronal representations or maps of visual space that depend on precise connections between retinal axons and their targets cells in adjacent layers of the lateral geniculate nucleus of the thalamus (28). An important issue in understanding the function of the primary visual cortex is how the several efferent neuron groups merge in thalamocortical channels and project to the extrastriate cortex (29). An image of the visual world is not impressed upon the retina but is assembled together in the visual cortex such that many of the visual phenomena traditionally attributed to the eye actually occur in the cortex (Figure 9) and exist as a function of the integration of human brain (30). Interactions between the intrinsic properties of thalamic neurons and reciprocal intrathalamic circuitry lead to the generation of slow oscillations that mediate physiological and pathophysiological behaviors (31). The central integration of intrathalamic circuitry has a probability of dependency on multimodal prethalamic integrators such that changes in the frequency of firing of one modality might affect the cortical expression of another. For instance, spontaneous activity and responses to sensory stimulation in ventrobasal thalamic neurons of rats produce both fast and slow potentials from cells whose axons take a rostrolateral course across the thalamus, with collaterals directed toward the reticular tha-

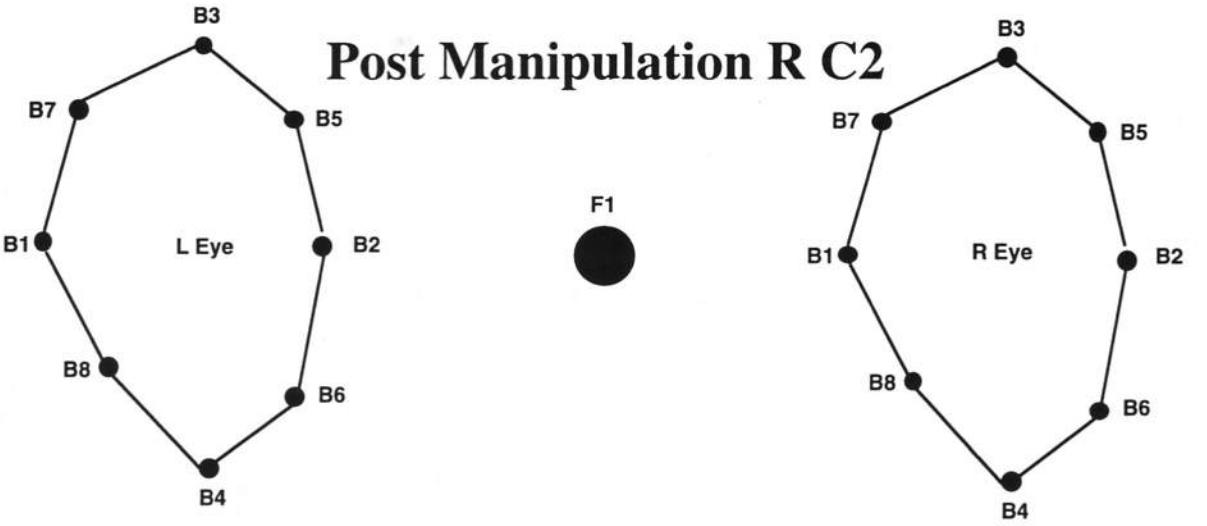


Fig. 11 *Post-manipulation right C2.*

lamic nucleus (32). Damage of the primary visual cortex in humans severely disrupts vision by disconnecting much of the cognitive-processing machinery of the extrastriate cortex from its source of visual signals in the retina and has system-wide repercussions on neural circuitry that includes the retina, thalamus, midbrain and extrastriate cortex (33). Other variables that affect the integration of central structures such as thalamus, midbrain and extrastriate cortex should also manifest as visual disturbances even if the disturbance cannot be perceived.

When visual pathways are regressed and incomplete, thalamic and tectal structures involved in form and motion perception undergo severe regression, which results in an absence of visual cortical potentials (34). It is suggested that there must be abnormalities in intrathalamic circuitry as a consequence of this regression that would affect other modalities not limited to the cortical expression of vision and that abnormalities of other systems would have central cortical effects not limited to the singularity of the modality. Mechanoreceptor stimulation in normal rats have demonstrated functional synaptic connections between brainstem and thalamic neurons; thalamic neuronal death is associated with thalamic hypometabolism (35). The death of thalamic neurons would result in decreased thalamocortical contributions with a probability of altered perception. The number and temporal structure of nerve impulses in response to a visual stimulation depend upon the general organization of the thalamic impulse trains (36). Nonvisual variables that alter thalamic impulse trains might alter visual perception.

The areal limits of the visual striate cortex are specified by the thalamic inputs so that afferent specification of the cerebral cortex appears as a general feature of mammalian development (37). Reflective study on developmental processes and comparative anatomy can facilitate the interpretation of clinical phenomenon associated with human cortical events. The finding that the adult nucleus geniculatus lateralis dorsalis, pars

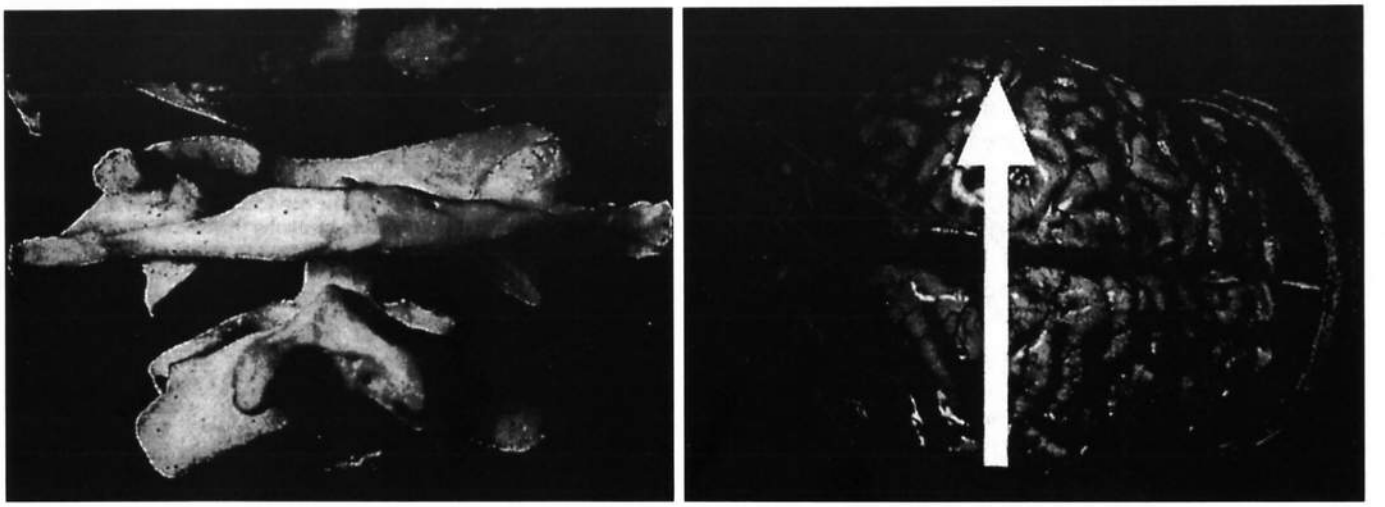


Fig. 12 *Manipulation can increase brain activity.*

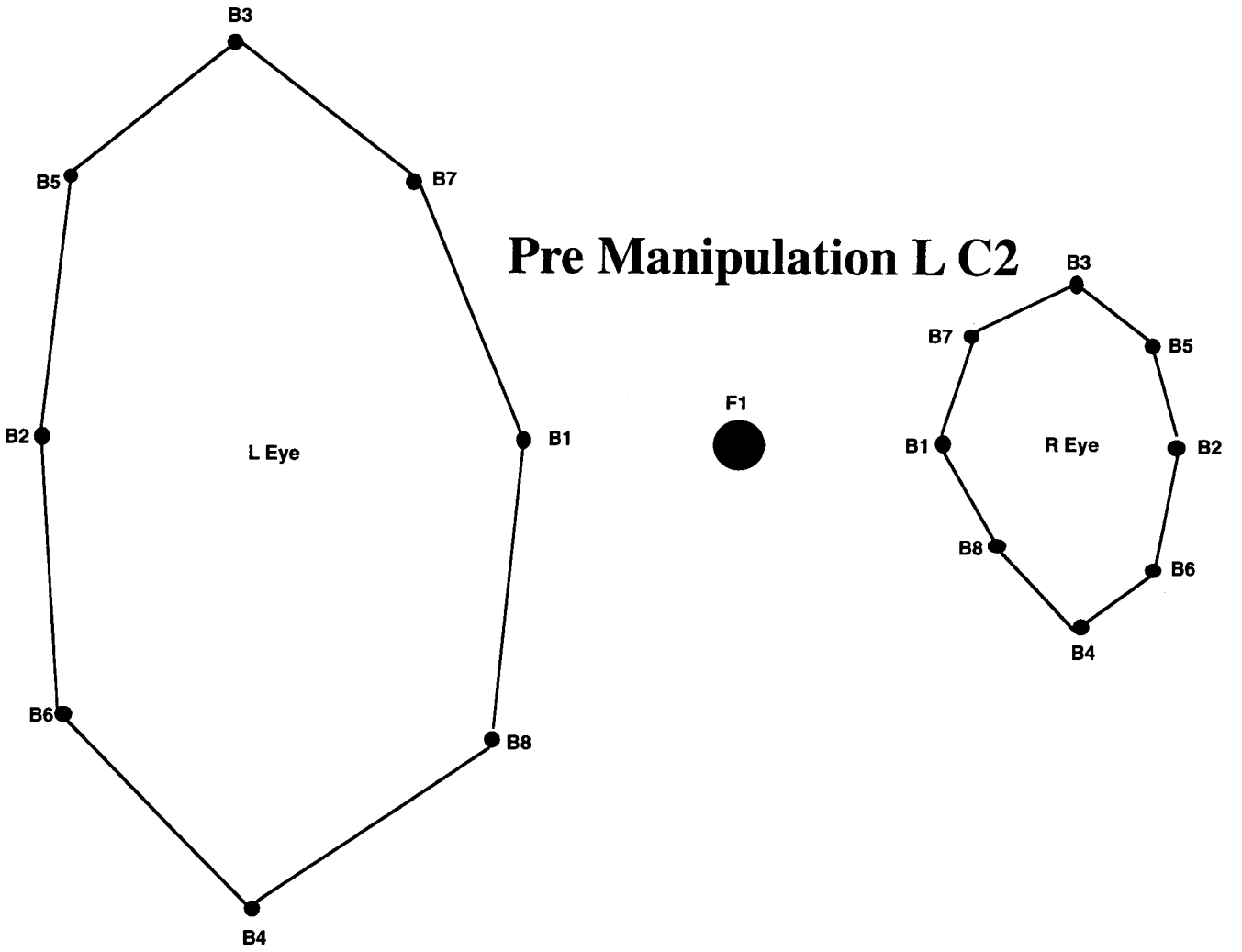


Fig. 13 *Premanipulation left C2.*

ventralis of the turtle (*Emys orbicularis*) arises from one of the migrations of the dorsal thalamus assists in the debate over the possible homologues of the mammalian geniculostriate visual pathway and supports thalamically mediated control on the visual cortex (38). A thermodynamic model of geniculate morphogenesis supports the hypothesis that the blind spot traps the transition in its stereotypic position by introducing a singularity in an otherwise smooth gradient in forces, guiding the development of thalamic morphogenesis, which suggests that small-scale anomalies may be important in the determination of large-scale patterns in biological structure (39).

The development of the thalamus and its ability to become an integrator is pivotal in the understanding of the cortical integration of multimodal environmental potentials. For example, the lateral region of the visual pulvinar complex in monkeys adjoins the lateral geniculate nucleus of the thalamus and has relationships to the visual cortex associated with the peripheral locations of the visual field associated with blind spots in humans (40). Distinct programs of axon arbor development suggest that the periods of susceptibility of geniculocortical axon arbors to postnatal influences of the environment result in plastic responses (41). The continuum of multimodal afferentation to the nervous system suggests that activity-dependent changes will result in perceptional development that may continue throughout the lifespan. The presence of highly ordered connectivities is a basic characteristic of the central nervous system and is a prerequisite for its proper function. The elaboration of precise topographic projections includes activity-dependent developmental plasticity (42), which is ultimately dependent upon environmental potential experiences. For instance, there is a substantial reorganization of cortical somatosensory topography after upper limb deafferentation, and this massive somatosensory plasticity in human adults suggests a mechanism for the perceptual changes that occur in deafferentated states (43).

Brain activity occurs as a function of an integrated response to multimodal environmental dependent activity. Changes in the frequency of firing of synaptic integrators of the brain associated with an environmental receptor potential should change the frequency of firing of the cerebral cortex customarily dependent on the generation of different receptor potentials. Although a specialized brain function such as vision is

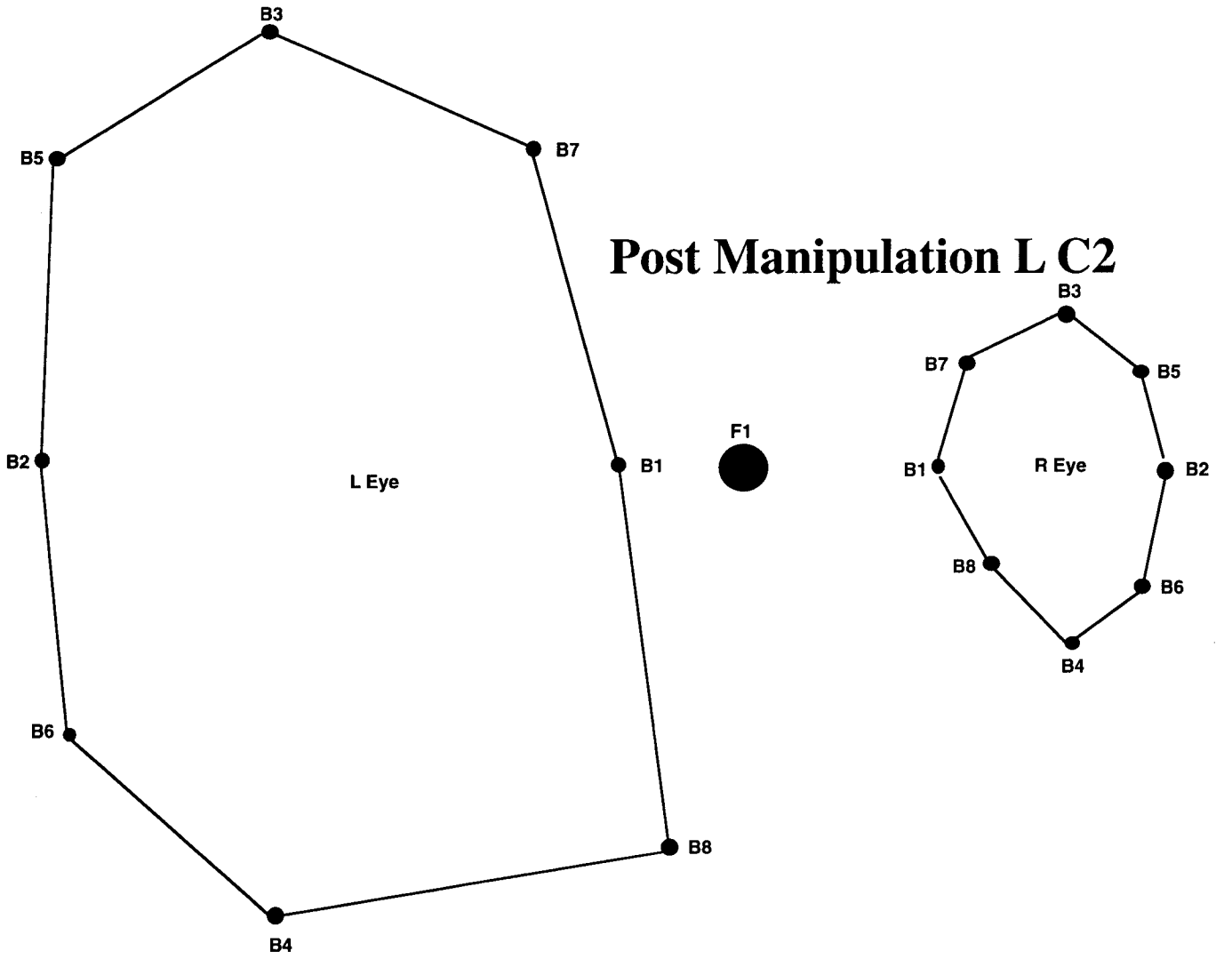


Fig. 14 *Post-manipulation left C2.*

associated with and dependent upon a specific receptor-based system, the central integration of multimodal receptor-generated activity should promote increased visual experience despite a steady state of afferentation from photic environmental stimuli. A change in the frequency of firing of one receptor-based neural system should effect the central integration of neurons that share synaptic relationships between other environmental modalities, resulting in an increase or decrease of cortical neuronal expression that is generally associated with a single modality.

The clinical effects of manipulation of spinal joints resulting in changes in human perceptual experience must occur as a consequence of changes in brain activity. There has been a need for an experimental model that can demonstrate changes in brain activity as a consequence of spinal joint manipulation. Visual information from the environment affects cortical activity as a consequence of a graded response of the photoreceptors of the retina. A change in visual experience generated by a maintained photic stimulation after spinal manipulation would represent changes in cerebral cortical activity as a repercussion of the neurological consequences of the spinal joint manipulation. A model measuring brain activity using visual experience as a controlled standard has enabled the development of methodology that measures change in the activity of the human cerebral cortex as a consequence of spinal joint manipulation.

The use of the blind spot as a window of human perceptual experiences can facilitate the study of possible integrators of a perceptual experience that previously were not considered in concert. Immediate changes in the blind spot can be mapped with ease and compared to previous maps obtained before manipulation of a variable. This model will enable the observer a mechanism to measure the central integration of multimodal potentials in the general patient population without a dependency upon invasive methodology.

Manual perimetry blind spot mapping is a simple and cost-effective way to measure integrated cortical activity. It is a highly reproducible method of measuring cortical activity that

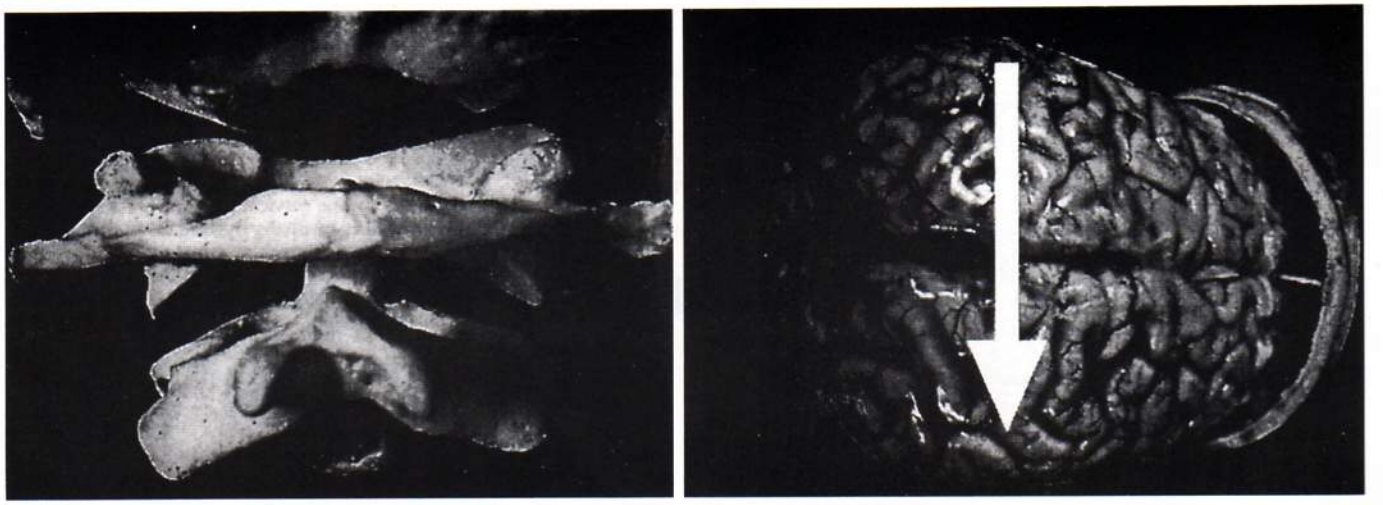


Fig. 15 *Manipulation can decrease brain activity.*

seems to be a result of multimodal integrators and can assist in the direction of methodology that can change the function of the cerebral cortex. Manipulative reduction of the second cervical motion segment on the side of an enlarged blind spot or on the side opposite decreased brain hemisphericity is associated with reduction of the size of that blind spot and an increase in contralateral brain activity (Figures 10–12). Manipulative reduction of the second cervical motion segment on the side opposite the enlarged blind spot or on the side of decreased brain hemisphericity is associated with an increase in the size of the enlarged blind spot and decreased summative brain function, creating an even larger map (Figures 13–15). Manipulative reduction of the second cervical motion segment is specific for brain hemispheristic summation and was associated with changes in the blind spot of only one eye without affecting the size of the blind spot from the other eye. This suggests that the mechanism of blind-spot changes after manipulation are directed by specific canalized neurological pathways and not by chance. Manipulation of the second cervical motion segment using the coupled technique of Carrick (44–47) on the side of an increased blind spot seems to effect an increase in synaptic excitatory integration at the contralateral visual cortex, decreasing the size of the previously enlarged blind spot. Manipulation of the second cervical motion segment using the coupled technique of Carrick (44–47) on the side opposite of an increased blind spot seems to effect a decrease in synaptic excitatory integration at the visual cortex associated with an increase in the size of the previously enlarged blind spot. The changes in perceptual experiences (decreased or increased blind spot) that were demonstrated after the manipulative reduction of spinal joints probably occur as a consequence of a change in the firing rate of cortical neurons resulting in different probabilities of summation.

CONCLUSION

Although the mechanisms of neuronal summation are in themselves multimodal, it is suggested that manipulative reduction of the second cervical motion segment on the side of an enlarged blind spot evokes primary afferents from joint receptors that affect in part the ipsilateral cerebellar projections to the contralateral thalamocortical pathways and the contralateral thalamocortical tracts from second-order projections of primary afferents from spinal joint and muscle spindle receptors. The relationship of somatosensory evoked potentials and visual summation suggest the presence of multimodal, dependent, intrathalamic projections. It is also suggested that the benefits of spinal manipulative therapy are not limited to musculoskeletal or neuromuscular conditions suffered by humankind and that clinical results reportedly attributed to spinal manipulation occur as a consequence of the integration of variables that sum to promote human brain function. Clinicians who use spinal manipulative procedures should realize that these procedures may be associated with an increase or decrease in brain function dependent upon the previous cortical hemisphericity of a patient and the side of the neck that is manipulated. Manual perimetry measurement of blind spots provides reproducible data representing the integrative activity of the human brain and may be used as an instrument to observe and compare change associated with a controlled modality. The use of methodology developed in this research is appropriate for other applications where there is a question of central effects on the brain activity of the modality.

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