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Tactile exploration of space and visual neglect in brain-damaged patients*

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Summary. A maze test of tactile scanning was used to investigate the relationship between visual neglect and the tactile modality of space exploration in 46 patients with right-sided brain damage (RBD) (20 with and 26 without visual neglect), 27 patients with left-sided brain damage (LBD) and 30 controls. Both LBD and RBD patients that were free from visual neglect more frequently used the tactile mode to explore the space contralateral to the sound hemisphere, while the RBD patients affected by visual hemi-inattention preferred tactile scanning of the left, visually neglected, half of space. Some implications of these findings are discussed. In particular, the modality-specific nature of neglect phenomena and the possibility of tactile compensation are suggested.

Key words: Space exploration – Visual neglect – Tactile scanning

Introduction

Unilateral neglect is characterized by the failure to attend to the side of extrapersonal space contralateral to the affected hemisphere in some brain-damaged patients [8, 27]. While slight signs of hemi-inattention for the contralateral half of space may occur following lesions to either cerebral hemisphere, characteristic instances of unilateral neglect are classically associated with right parietal injury [8, 17]. Thus such a patient may leave the left half of drawings unfinished, fail to read the left part of the title of a newspaper or ignore the contents of the left-hand side of a dinner plate [12].

Hypotheses so far advanced ascribe this syndrome to disordered sensory input [2, 3, 11], hemispatial attentional-intentional dificit [18, 19], oculomotor disorders [23, 24], or unilateral defect in space representation [4, 5].

Each of these hypotheses remains open to debate in view of the evidence of the complexity and, perhaps, the heterogeneity of the phenomenon. In this connection it is of interest whether unilateral neglect occurs even when the role of vision is excluded and extrapersonal space is explored tactually. This aspect is little known because the syndrome has nearly always been studied with tasks, such as drawing, visual searching and reading, that require space exploration through vision. The problem is of relevance because the tactual scanning of space, carried out without involvement of oculomotor mechanisms and without directional control of visual attention, could provide information about a modal or transmodal nature of hemi-inattention. In fact, if it were demonstrated that signs of unilateral neglect occur even when only the tactual modality is used, it would be reasonable to infer that the disorder has transmodal features and it is very likely an expression of a basic disturbance of space representation.

Up to now two studies have been carried out in this field. The first [14] showed that both patients with left-sided and right-sided brain damage (LBD and RBD patients) manifest a significant impairment in tactile exploration of the half of space contralateral to the damaged hemisphere and suggested that the disorder is more prevalent after right posterior injury. The second [10] failed to confirm the conclusion of the first study and did not support the existence of a clear relationship between visual neglect and abnormalities in tactile scanning of space.

However, the impression we gained from both these studies is that the evidence for or against correlations between visual neglect and defects of tactile exploration is indirect because comparison was carried out between patients selected according to the hemispheric side of lesions and the presence or absence of visual field defects and not following the criterion of the presence or absence of visual hemi-inattention. Although visual field abnormalities and visual neglect are often closely correlated, they are substantially different and independent phenomena [8, 27]. We therefore studied the relationship between visual neglect and tactile exploration of space by comparing groups of brain-damaged patients selected for the presence or absence of visual hemi-inattention.

Patients and methods

Thirty control subjects (18 males and 12 females) without past or present evidence of any disease involving the central or peripheral nervous system and 73 stroke patients (46 males and 27 females) admitted to the Neurology Department of Catania University between March 1983 and April 1985 took part in the study. All subjects were right-handed on Oldfield's Inventory [29] and had had at least 5 years of education. On admission to hospital each patient received detailed neurological examination and skull radiography, electroencephalography, CT scan, electrocardiography and blood tests were carried out. Patients with an equivocal diagnosis, those with CT scan evidence of bilateral lesions or cerebral atrophy, those

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with a past history of stroke and, finally, patients affected by mental changes or general health problems precluding testing were excluded. The subjects who passed these selection criteria were subdivided according to:

A. The hemispheric side of lesions, suggested by the neurological examination and confirmed by CT. Thus, 46 RBD patients and 27 LBD patients were selected.

B. The presence or absence of visual hemi-inattention, assessed by means of the line crossing-out test described by Albert [1] and the drawing copying test (in this case the patient was asked to draw, successively and on separate sheets of unlined white paper 21.5 × 28 cm, a flower, a house, a clock-face with the numbers and a cross). Patients who omitted one or more segments in any of the sections of Albert's test and, in addition, failed to complete, on the same side, any one of the four drawings, were classified as showing unilateral visual neglect. According to this criterion a diagnosis of more or less severe left visual neglect was made in 20 patients with right hemisphere damage. On the other hand, none of the 27 left hemisphere patients showed signs of right visual neglect. Although many produced poor drawings, they were not incomplete on the right. Furthermore, Albert's test was performed very well by the subjects of this group.

C. The presence or absence of homonymous visual field defects, investigated by confrontation and, where appropriate, perimetry.

In this way the following groups were formed:

1. RBD patients with left visual neglect and hemianopia ranging from very mild to severe (RBD patients VN+ H+): 13 subjects, average age 65.1 ± 8.7 years.

2. RBD patients with left visual neglect but without hemianopia (RBD patients VN+ H−): 7 subjects, average age 68.4 ± 4.9 years.

3. RBD patients without visual neglect but with hemianopia (RBD patients VN− H+): 11 subjects, average age 63.7 ± 9.2 years.

4. RBD patients without visual neglect and without hemianopia (RBD patients VN− H−): 15 subjects, average age 66.3 ± 6.2 years.

5. LBD patients with hemianopia (LBD patients H+): 12 subjects, average age 62.9 ± 7.5 years.

6. LBD patients without hemianopia (LBD patients H−): 15 subjects, average age 66.7 ± 11.4 years.

7. Normal controls: 30 subjects, average age 65.6 ± 8.4 years.

The following elements were surveyed in all the brain-damaged patients:

1. The intrahemispheric locus and extent of lesions reconstructed from CT scans, following the technique developed by Luzzatti et al. [25].

2. The degree of sensorimotor impairment using the standard method of Bisiach et al. [6]. On the basis of this method the asymptomatic patient had an index of 0, while the hemiplegic patient with total anaesthesia contralateral to the lesion scored a severity index of 12.

3. The presence or absence of aphasic disorders of language assessed by means of the Token test [13].

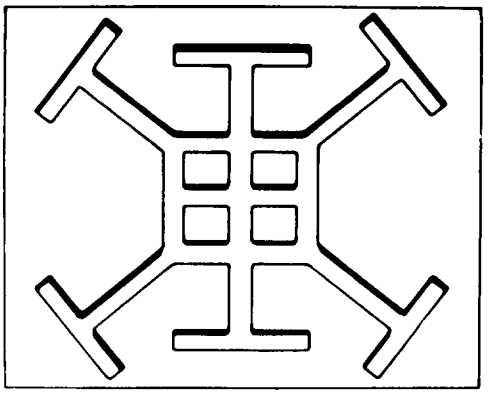

Fig. 1. The tactile maze (reproduced by permission of *Cortex* [14])

4. The characteristics of ocular movements on verbal command and pursuit.

There were no differences among the groups as far as average age and severity of sensorimotor deficit were concerned. The LBD group included 19 aphasic subjects (9 with and 10 without hemianopia). However, all these patients were able to understand and fulfil the requirements of the tasks involved in this study. On the other hand, none of the RBD subjects showed pathological scores on the Token test. The majority of the LBD patients with aphasia and hemianopia and the RBD group with visual neglect and visual field defects had, among the pathological groups, the most extensive lesions. This latter group, besides having wider lesions which were located in all cases in the posterior areas, had the highest percentage of subjects affected by more or less severe oculomotor disturbances (82.6%). All the subjects were tested individually. Neuropsychological assessment of the brain-damaged patients was carried out between 2 and 3 weeks after the stroke.

A modified version of the Tactile Searching test devised by De Renzi et al. [14] was used to assess the tactile modality of space exploration in our subjects. The modification adopted in this study consisted in recording the number of marbles reached in the right and left halves of space rather than the time spent in searching for a marble. This new measure has been considered a more reliable indicator of tactile neglect. The test consisted of a maze cut into a 50 × 40 cm board. The maze was made up of six symmetrical alleys, 2 cm deep and 2 cm wide, starting from the centre of the board. Four of them were obliquely oriented and ended with a lateral arm in the upper and lower left corners and in the upper and lower right corners respectively (Fig. 1). A marble was placed at one end of each lateral arm. The examinee entered the laboratory in such a way that he could not see the board. Then he was blindfolded and seated squarely in front of the maze.

Before the test the subject's hand was guided by the examiner along the edges of the board to familiarize him tactually with its dimensions. Then his forefinger was guided to the centre of the maze and he was asked to move it as quickly as possible along the alleys until he reached one of the marbles. Twenty-four trials were planned for each subject. The time limit was 3 min for each trial. When the subject reached one of the four marbles his forefinger was brought again to the centre of the maze and another trial began. The score was the number of times that the subject reached one of the marbles placed respectively on the right or left side of the maze, out of 24 trials. The search component of this procedure was pre-

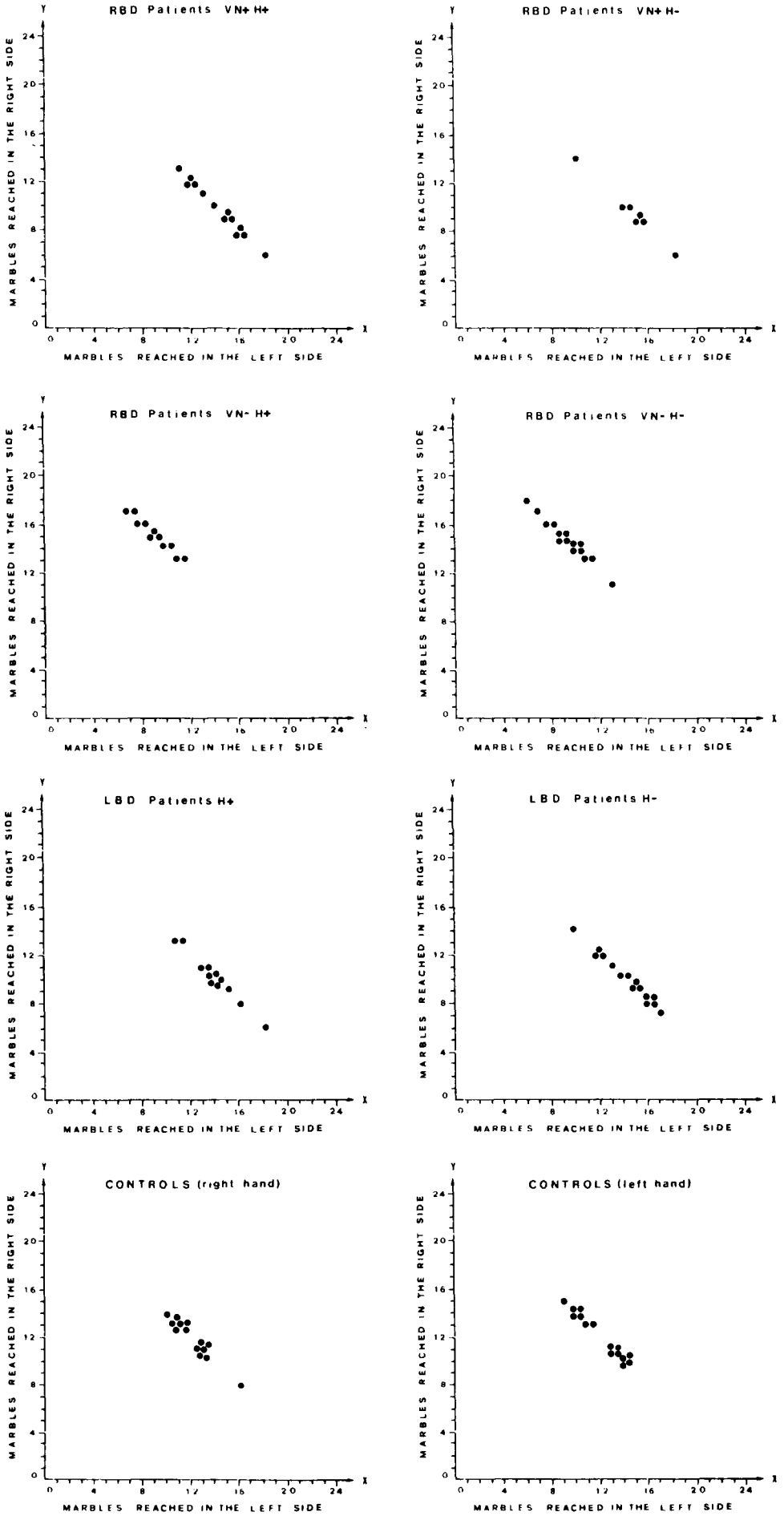

Fig. 2. Scatter diagrams of the individual scores of brain-damaged patients and of normal control subjects on the Tactile Searching test

Table 1. Mean number of marbles reached, per group, on each side of the maze. Mean right/left difference scores. For abbreviations, see text

	Left side (mean)	Right side (mean)	Standard deviation	Mean right/left difference
RBD patients VN+ H+	14.23	9.77	2.09	4.46
RBD patients VN+ H−	14.43	9.57	2.37	4.86
RBD patients VN− H+	9.00	15.00	1.41	−6.00
RBD patients VN− H−	9.33	14.67	1.71	−5.34
LBD patients H+	13.92	10.08	1.93	3.84
LBD patients H−	14.20	9.80	2.01	4.40
Controls (right hand)	12.27	11.73	1.58	0.54
Controls (left hand)	11.93	12.07	1.83	−0.14

Table 2. Spatial side preference of brain-damaged patients and of normal control subjects on the Tactile Searching test. Statistical analysis (Walsh test, two-tailed). For abbreviations, see text

	No. of subjects	Right side		Left side	
		α	Observed values	α	Observed values
RBD patients VN+ H+	13	0.047	7, 6	0.020	2, 1[a]
RBD patients VN+ H−	7	0.047	6, 9	0.047	4, 0
RBD patients VN− H+	11	0.011	−4, −2[a]	0.056	−6, −8
RBD patients VN− H−	15	0.010	−4, −2[a]	0.047	−8, −7
LBD patients H+	12	0.048	4, 8	0.011	1, 2[a]
LBD patients H−	15	0.047	4, 5	0.020	1, 1[a]
Controls (right hand)	15	0.047	3, 1	0.047	−1, 0
Controls (left hand)	15	0.047	0, 0	0.047	−1, −1

[a] Significant (the significance levels are given by α)

served by the fact that the examinee ignored both the number and the position of the marbles in the maze. Furthermore, after each trial the marbles were shifted from one to the other extreme of the lateral arms so as to minimize the risk of a learning effect across the trials.

All the brain-damaged patients suffered from a more or less severe motor impairment and performed the test with the unaffected hand (that is, the hand ipsilateral to the diseased hemisphere), while half of the control group (15 subjects) used the right and half the left hand.

Before the test session each subject received a blindfolded training on a very simple maze. The training was continued until it was evident that the subject had understood the task.

Results

All the subjects were always able to reach one of the four marbles within the 3-min time limit. Thus there were no omissions. Moreover, none of them showed any relevant learning effect across the trials by finding a route and sticking with it. In other words, the subjects were compelled to follow, trial by trial, a searching strategy for reaching one of the four marbles.

Figure 2 shows, for each group, the individual scores in the form of a scatter diagram. Table 1 gives the mean number of marbles reached in the right and left halves of the maze, out of 24 trials, and the mean right/left difference scores. It is apparent that the brain-damaged groups, unlike the control group, showed a side preference for their searching.

The first statistical analysis was designed to elicit any significant difference in scanning by spatial side, for each group. As in a symmetrical exploration half the marbles are reached on each side of the maze, we compared the individual scores by the Walsh test (two-tailed) [32].

The data of this analysis, shown in Table 2, may be summarized as follows:

1. The control group, regardless of the hand used, reached nearly the same number of marbles on each half of the maze.

2. The RBD patients differed in their preferred hemispace according to the presence or absence of visual neglect. In particular, the RBD patients VN+ H+ preferentially reached the marbles placed in the left, visually neglected, half of space. A similar tendency emerged from the individual scores of the RBD patient VN+ H− (see Fig. 2) but it did not reach a statistically significant level. (It should be borne in mind that this group comprised only 7 subjects.) In contrast, the RBD patients without visual neglect (both H+ and H−) preferred to reach the marbles placed in the right hemispace.

3. The LBD patients, like the RBD patients VN−, showed a significant preference for the marbles ipsilateral to the diseased hemisphere.

The object of the second analysis was to compare the scanning behaviour of the seven groups. In this case, on account of their very high similarity, the two control subgroups were combined into a single group.

For each subject a laterality index was calculated according to the formula:

$$\frac{L-R}{L+R} \times 100,$$

where L and R are the number of marbles reached respectively on the left and right side of the maze. These indexes, submitted to analysis of variance (completely randomized design [9]), showed highly significant intergroup differences ($F(6,96) = 15.25$, $P < 0.001$). Subsequent multiple comparisons were carried out by Duncan's procedure. Probabilities of 5% or less were considered statistically significant. The main results can be summarized as follows:

1. The control group was found to differ significantly from all the others.
2. The visually inattentive RBD patients differed, in their tactile scanning, from the RBD patients without visual neglect.
3. Finally, the RBD patients without visual neglect were found to differ from the LBD subjects because each one of these groups preferred the tactile scanning of the hemispace ipsilateral to the diseased hemisphere.

The presence or absence of visual field defects did not affect the magnitude of these differences.

Discussion

The results described fail to confirm any correspondence between visual and tactile neglect and suggest, at least in our patients, the modality-specific nature of the syndrome. In effect, a substantial modification of tactile exploratory behaviour was observed in our subjects, after injury to either cerebral hemisphere, but it was not in the direction of any tactile negligence for the visually neglected half of surrounding space. In fact, our normal controls explored tactually the right and left halves of space in equal measure, regardless of the hand used for the purpose, which is evidence that with the cerebral commissures intact and in absence of focal lesions, scanning of extrapersonal space is the product of the integrated activity of both cerebral hemispheres, working together as an integral unit [30, 33].

On the other hand, both LBD and RBD patients, hemianopic or not, without signs of visual neglect, showed a significant impairment in the tactile exploration of the side of space contralateral to the damaged hemisphere (that is, the left side for the RBD patients and the right side for the LBD patients).

The same trend was described by De Renzi et al. [14] in their sample. Thus it would appear that injury to either hemisphere mainly impairs the mechanisms controlling that tactual exploration of the contralateral space [12, 14]. Some recent data [21] suggest that on tasks carried out through the tactile modality, the arm used to explore the surrounding space preferably operates in its own "compatible" hemispace (that is, the right arm in the right hemispace, the left arm in the left hemispace). In normal subjects, however, a continuous interhemispheric flow of sensorimotor and spatial information guarantees adequate tactile scanning even when the arms are crossed and operate within the "incompatible" hemispace. Hence, when the hemispheres are disconnected or a brain injury restricted to one hemisphere modifies this integrated mechanism, impaired exploratory behaviour lateralized to the "compatible" hemispace would be expected [21]. In the light of that, at least part of the tactile behaviour of our patients can be ascribed to imbalance of the motor systems controlling the distribution of movements of the exploring arm within the extrapersonal space.

As regards exploratory behaviour in the dark observed in our RBD patients with visual neglect (the data concerning the LBD patients are missing as no subjects with visual hemiinattention were found in this group), the scanning strategy of the vast majority of these subjects was just the reverse of that observed in the RBD patients without neglect since they preferred to use the tactile channel for exploring the left, visually neglected, half of space.

The results allow us to consider two specific issues: The first is that these patients, even if affected by left visual neglect, did not have any impairment of tactile exploration on the left side of the maze. The second is that they showed tactile compensation. These findings cannot be explained as consequent to visual field defects since similar tactile behaviours were common to patients with and without hemianopia.

Oculomotor disorders were present in 82.6% of our inattentive patients. However, the possibility that these defects might somehow have influenced the tactile strategy appears undermined by the fact that in the four patients without oculomotor disturbances the scanning behaviour was of the same type as that shown by the entire group of patients.

Previous studies [10, 16] have reached the conclusion that unilateral defects in space exploration are mostly induced by vision. Chedru [10], for instance, stressed the absence in the vast majority of his RBD patients affected by visual neglect, of any impairment in tapping, blindfolded, the left-sided keys of a teletype and suggested "..that unilateral defect in manual exploration of space is induced by vision and that consequently space representation, per se, is not altered in unilateral spatial neglect".

In a similar way, at least three studies, published in the last few years [7, 15, 31], failed to confirm any significant coincidence between auditory extinction and unilateral auditory neglect on the one hand, and visual neglect on the other. In particular De Renzi et al. [15] stressed the very marked dissociation observed in some patients of their series who showed severe visual neglect but did not extinguish in the auditory modality. They suggested, therefore, that these deficits are probably modality-specific and contingent upon the "disruption of discrete anatomical substrates, specific for each modality". Likewise, our results fail to support any transmodal nature for the visual neglect observed in our hemisphere-damaged sample.

As regards the interpretation of our data in the light of the hypotheses advanced to explain neglect phenomena, our failure to confirm any correlation between visual and tactile neglect is not conclusive. However, the modality-specific nature of many forms of hemi-neglect should be taken into account for the understanding of the syndrome. For instance, if we refer to neglect as an attentional deficit, it would be reasonable to assume that, in general, attentional processes have modality-specific features so that they may be selectively disrupted by a naturally occurring lesion [15].

As regards the surprising result that the RBD sample with visual neglect appeared more inclined to use the tactual exploration of the visually neglected half of space, this finding is not inconsistent with the view that there may be dissociable and

modality-specific neglect phenomena with an intact modality able to compensate for the defective one.

There are some neurophysiological observations that may support this hypothesis. It is well documented [20, 22, 26, 28] that contiguous and physiologically related parietal areas of each hemisphere (areas 5, 7a, 7b, inferior parietal lobule) process and integrate tactual and visual information, both of ipsilateral and contralateral spatial origin. Furthermore, Plourde and Sperry [30] suggest that "..the left hemisphere possesses adequate mechanisms for attending to, and acting in, both halves of space".

In the light of these data it is conjectured that in our RBD patients with visual neglect the sound hemisphere, through the contralateral arm, was able to attend to the left, visually neglected hemispace, showing a compensatory utilization of the tactile mode.

Acknowledgement. The tactile maze, reproduced in Fig. 1, was previously published: De Renzi E, Faglioni P, Scotti G (1970) Hemispheric contribution to exploration of space through the visual and tactile modality. Cortex 6:195

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