Neuropsychologia, 1971, Vol. 9, pp. 273 to 280. Pergamon Press. Printed in England

LANGUAGE AND SPEECH CAPACITY OF THE RIGHT HEMISPHERE*

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(*Received* 8 *February* 1971)

Abstract—Right hemisphere language and speech capacity was further analyzed in brain-bisected patients. The results indicate that little or no syntactic capability exists in the right hemisphere. The only semantic dimension that was comprehended in a series of pictorial-verbal matching tests was the affirmative-negative. Moreover, earlier indications of a right hemisphere speech capacity could not be confirmed. Differences in verbal reaction time to visual stimuli projected to right and left hemispheres were alternatively interpreted as consequences of subcortical transfer mechanisms or cross-cuing strategies.

INTRODUCTION

MOST of the prior studies of language and speech function in brain-damaged man have emphasized the well-accepted notion of cerebral dominance [1]. The vast majority of language and speech function was considered to be a product of only the left hemisphere. While cases of right hemisphere participation in language and speech activities in left-handed patients were frequently reported, the studies of MILNER [2] employing unilateral injections of sodium amytal further underlined the predominant role played by the left hemisphere in language and speech, no matter what the hand preference.

This view has prevailed despite general agreement that the right hemisphere is potentially capable of almost normal language and speech function. Numerous hemispherectomy studies have pointed out how the right hemisphere can assume these duties with little or no difficulty if the insulting events to the left hemisphere occur at an early age [3]. Nonetheless, for largely unexplained reasons, language and speech mechanisms in normal development become almost exclusively the property of the left side of the brain.

It is in this context that some earlier studies on language function of the right hemisphere in brain-bisected man were carried out [4]. These patients offer a unique opportunity to examine the intact right half-cerebrum without the usual complications of gross brain damage. In brief, because the minor hemisphere had displayed a remarkable aptitude for matching lateralized visual and stereognostic information [5], further tests were designed to explore the possibility of language functioning. It was discovered that some (but not all) of these patients possessed a limited language capacity in the right hemisphere, the most demonstrable aspect of which was an ability to recognize simple nouns. When the word "spoon" was flashed to the right hemisphere, the left hand would respond appropriately by

* Aided by USPHS Grant No. 1 ROL MH17883-01 NP awrded to M. S. GAZZANIGA and NASA Grant NGR-05-009-083 awarded to ROBERT GALAMBOS at UCSD.

retrieving a spoon from a series of objects placed out of view. Strict limits seemed to apply, however, to the class of nouns that could be identified. Those that were evidently derived from verbs were not acted upon easily. For example, matches involving "—er" nouns such as "butter" and "water" went well, but those with other bimorphic nouns such as "teller" and "trooper" did not [6].

While the comprehension of nouns was demonstrated through both auditory and visual channels, there was little or no evidence that patients were able to respond appropriately to simple printed *verbal commands* [6]. The instructions "tap", "smile", "frown", "hit", etc., left the patient dumb and mute when flashed to the right hemisphere. Thus, while the minor hemisphere did have the ability to recognize nouns, the simplest verbs seemed to be outside its repertoire of language activities.

The present studies explore further the upper limits of semantic and syntactic structure within the right hemisphere. Comprehension of simple sentences containing active, passive, future, and negative constructions was tested, along with the distinction between singular and plural nouns. A second series of tests examined in detail a possible case of speech output by the right hemisphere.

OBSERVATIONS

Language capability

These tests were carried out in the two most language-rich patients in the group (L.B., age 17 and N.G. age 35). Both subjects were normally right-handed. In L.B. the tests occurred some 3 yr. post-operatively and in N.G. approximately 6yr. Pre- and post-operative I.Q. scores did not greatly vary overall on both subjects, with N.G. scoring in the 70's and L.B. around 115. Both patients were extremely alert and well trained in the general testing techniques.

Simple pictures depicting various actions were quick-flashed to the right hemisphere by limiting the projected information to the left visual field. In brief, the subjects fixate a point and when fixation has been assured by observation, the stimulus is flashed at a short duration (100 msec) so as to disallow eye movements and the concomitant failure in stimulus lateralization [6].

After each trial the patient was asked whether the scene represented one of two conditions. For example, a picture of a boy kissing a girl was flashed to the left visual half-field, and the patient would characteristically say he saw nothing, or simply a brief flash. The examiner would then ask which is correct, "The boy kisses the girl" or "The girl kisses the boy"? This examination technique made use of the fact that only the right hemisphere saw the "question", while both heard the alternative answers.

Both subjects proved unable to make such distinctions, whether they were phrased in either active or passive tense. If the choice was between "The girl was kissed by the boy" vs. "The boy was kissed by the girl", equally poor performance was seen, with the patients' guesses made on each trial never exceeding chance levels of correctness. As mentioned in the foregoing, the right hemisphere did routinely respond correctly when test pictures that could be labelled with simple nouns were shown, and hence was quite capable of distinguishing between a boy and a girl *per se*. If a simple picture of a boy was shown to the right hemisphere, the subject would retrieve a card with "boy" printed on it or react to the spoken word "boy" when a series of alternatives were read aloud. The deficit in understanding the more complex pictures is therefore not in the perceptual sphere, but rather in the ability to use the subject–predicate–object logic of language appropriately to represent the pictorial action sequence.

The future tense was also not recognized and applied correctly. For example, a picture of a girl drinking a glass of water was followed by the query, "Which is correct? The girl is drinking or the girl will drink?" On a subsequent trial the same question was asked when the lateralized visual stimulus had been a girl holding a glass ready to drink. In all these tests, the right hemisphere did not make the appropriate distinctions at better than chance level.

Further testing demostrated an inability to differentiate between spoken singular and plural nouns. When a picture of a dog jumping over a fence or one of several dogs jumping over was shown, the patients proved unable to distinguish between the spoken alternatives, "The dog jumps over the fence" vs. "The dogs jump over the fence."

The only "higher" grammatical dimension tested that was understood by the right hemisphere was the affirmative vs. negative. When a picture of a girl either sitting or not sitting was followed by the spoken alternatives "The girl is sitting" and "The girl is not sitting", the correct one was selected. Both subjects performed almost perfectly on these positive-negative discriminations, despite their complete failure with the other aspects of language.

In summary, the right hemisphere is capable of recognizing noun objects, but cannot comprehend verbs or respond to printed commands. In the more complex sematic syntactic sphere, there is no ability to recognize either the relations between subject, verb, and object, the future versus the present tense, or the singular versus the plural case. It has remarkable ability, however, to discern whether an action sequence is properly represented by an affirmative or negative sentence.

Speech capability

Until recently there has been little reason to believe that the right hemisphere is able to initiate speech by itself. In numerous tests there were no indications that the right side was contributing directly to the patient's spoken responses [4]. Some more recent obesrvations, however, have opened the question of whether the normally mute hemisphere can be induced to "talk" under special conditions [7, 8, 9]. In the following experiments an apparent instance of right hemisphere speech that occurred during a number recognition task was analyzed by making reaction time (RT) measurements on the verbal responses.

During the course of studying the electrophysiological correlates of lateralized perceptual processes in the separated hemispheres [10], it was noticed that two of the four patients studied could easily identify verbally which of two simple numerical stimuli had been presented in the left visual half-field. This seemed to represent a new development. These were the youngest patients of the group (L.B., age 17, and C.C., age 19) who had both received the commissurectomy at age 12. The two patients who failed at this task were between 35 and 40 years of age, and had been bisected for about five years.

In these tests the subjects were required to distinguish between the numbers "1" and "0", flashed for 100 msec at five degrees to the left or right of the fixation mark. Eye movements were monitored by the electro-oculogram to ensure that no corrective shifts of gaze were being made. Varying the brightnes s of the stimulus lights and placing them 10–15 degrees from the midline did not disrupt the correctness of the spoken "one" and "zero" responses.

Verbal reaction time (*RT*). The subjects were told in advance that the numbers "1" and "0" would be flashed at random on either side, and that they were to say "one" or "zero" accordingly, as fast as they could. Inter-flash intervals varied randomly between 4 and 10 sec. The RT on each trial was measured from the onset of the stimulus light to the beginning of the speech waveform envelope, which wastape-recorded along with stimulus markers.

Table 1. Discriminative verbal RT's (in msec) to numerical stimuli flashed for 100 msec into the right and left visual half fields

		R. Visual Field		L. Visual Field	
	stimulus number	mean	s.e.	mean	s.e.
A. Subject L.B.	"1"	629	31	824	48
	"0"	693	39	956	46
	Both	661		890	
	stimulus number	mean	s.e.	mean	s.e.
B. Subject C.C.	"1"	721	89	1104	116
	"0"	811	71	987	102
	Both	766		1045	
	stimulus number	mean	s.e.	mean	s.e.
C. Subject L.B.	"2"	645	22	885	42
	"4"	656	12	889	53
	Both	651		887	

The verbal RT's for stimuli presented in the two visual half-fields are compared in Table 1. In subject L.B. the average RT was incremented by more than 200 msec when the flashes were delivered to the right hemisphere. This interhemispheric difference was highly significant overall [$F(1, 72) = 31{\cdot}05$; $p < 0{\cdot}001$], and for both "1" and "0" stimuli. In addition, RT's were longer for the "zero" responses (825 msec) than for the "ones" (726 msec) [$F(1, 72) = 5{\cdot}69$; $p < 0{\cdot}05$], although the stimulus number-visual field interaction was not significant, [$F(1, 72) = 0{\cdot}68$]. In subject C.C. the results were similar, but the mean RT in this case was 279 msec faster to numbers flashed to the left hemisphere [$F(1,43)=8{\cdot}15$; $p<0{\cdot}01$]. This interhemispheric difference was greatly augmented for the "1" (383 msec) relative to the "0" (176 msec), but the interaction between stimulus number and visual field did not reach significance due to the large error variance [$F(1, 43)=1{\cdot}12$].

To investigate whether these consistently delayed responses to left visual field stimuli reflected a sluggish speech system in the right hemisphere or a transfer of information over to the left, an additional series of visual recognition tests were performed in L.B. In the first, he was told that the 1–0 discrimination was to be continued, but in fact the additional numbers 2, 3, 5, and 8 were included without his knowledge to the set flashed to the right hemisphere. His standing instructions were to state which number had been flashed. Upon the first trial with a new, unexpected number there was a dramatic effect: the subject became agitated and exclaimed, "I beg your pardon". The examiner replied, "Just tell me what number you see." After a hesitation he said: "It looked like a six." In fact, the number had been a "2". On every subsequent trial with new numbers, however, he gave the correct answer after a considerable pause. During this interval between stimulus and response the experimenter noticed that rhythmical mouth movements were being made, but the cessation of all discernable movement at the experimenter's urging did not disrupt correct identifications.

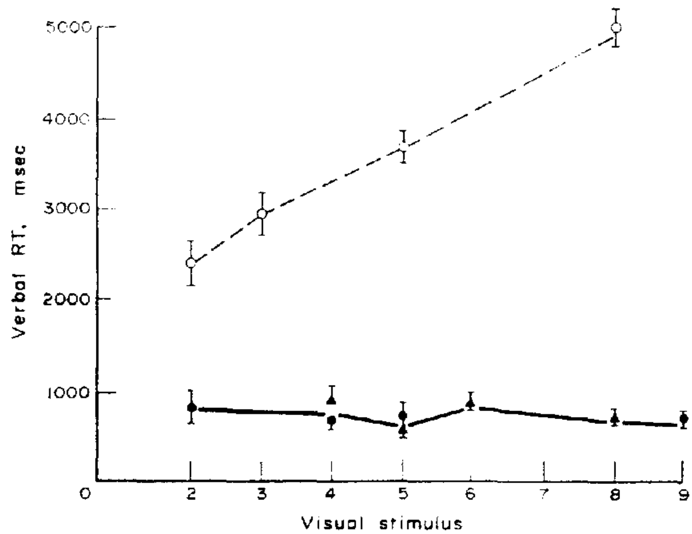

FIG. 1. Discriminative verbal RTs in response to each of a set of four visual stimulus numbers flashed to the right hemisphere (open circles) and to the left hemisphere (solid circles, series 1; solid triangles, series 2). Vertical bars give standard error of each mean RT.

An identification of the subject's strategy for recognition of these numbers is given by the RT data shown in Fig .1 (open circles). There is a nearly linear increase in RT as a function of the size of the number, suggesting that some kind of rhythmical counting strategy was being employed. This was verified by the subject's report, volunteered after the series; he stated that "What I do (meaning what the left hemisphere does) is to count up until I hit a number that 'sticks out.' Then I stop and tell you what it is."

In a further test, using the same set of numbers flashed to the right hemisphere, his per cent correct fell to chance levels when immediate verbal responses were demanded. This indicates that a cross-cuing strategy involving counting by the left hemisphere was essential for making the identification. As a control, when equivalent sets of stimuli (4,5,6,8 and 2,4,5,9) were flashed to the *left* hemisphere in two further runs there was no relation between response delay and stimulus number (Fig. 1, solid points).

In a final verbal test, the patient was informed that either a "2" or a "4" would be flashed to the right or left at random and he must respond instantly without using his counting tactics. With the set of alternatives now reduced to two, identifications of left visual field stimuli became 100 per cent correct and RT's were much faster than with the four unknown alternatives (Table 1C). These RT's were highly similar to those obtained in the 1–0 discrimination (Table 1A). Responses to numbers flashed to the right hemisphere were delayed by an average of 236 msec relative to left hemisphere presentations, a highly significant discrepancy [$F(1,21)=38{\cdot}08$; $p<0{\cdot}001$]. Response speeds did not differ between the "2" and "4" and there was no interaction between number and visual field.

To summarize the verbal RT experiments, subjects were perfectly capable of identifying numbers flashed into the left visual field, but a markedly longer RT was required than with right visual field stimuli. When there were only two alternative discriminanda, both known to the subject, RT's for stimuli to the right hemisphere were delayed by some 175–300 msec; with four stimulus alternatives (not known in advance) correct identifications required from one to several seconds depending on stimulus magnitude, and seemed to require a cross-cueing strategy.

Motor RT. A further comparison of the two hemispheres' visual recognition and motor execution speeds was made by requiring subject L.B. to make manual response to the numerical stimuli. The response, requiring distal musculatures, consisted of the thumb pressing a pushbutton mounted at the end of a cylindrical tube held in the hand. As in the verbal task, the numbers "1" and "0" were flashed to either visual field at random and a balanced series of responses made by either the right or left hand was obtained. The rask was to press "as fast as you can" for the "1" and to make no response for the "0", so that pattern tather than simple light information must be utilized for correct performance.

Table 2. Motor RT's for lever presses made by right and left hands, to the number "1" flashed into either right or left visual fields

		R. Visual Fields		L. Visual Field	
		mean	s.e.	mean	s.e.
Subject L.B.	R. Hand	435	21	502	36
	L. Hand	449	23	437	20

No errors were made in a series of 100 trials, and the RT's for the various field-hand combinations are given in Table 2. The overall F ratio for this table was not quite significant [$F(3,46)=1{\cdot}50$; $p>0{\cdot}10$], but nonetheless, the RT for the left field-right hand combination was significantly longer than the average of the other three [$F1,46)=4{\cdot}13$; $p<0{\cdot}05$]. In other words, when the left hand was in use, flashes to either hemisphere provoked equivalent RT's, but with the right hand there was a delayed response for stimuli entering the right hemisphere. It is also seen that the two "ipsilateral" combinations (right field–right hand, and left field–left hand) have faster RT's than the contralateral (left field–right hand, and right field–left hand) by 67 and 12 msec, respectively. Only the former difference attained statistical significance however [t(one-tailed)$=1{\cdot}83$, $df=23$, $p<0{\cdot}05$].

DISCUSSION

The foregoing studies clearly suggest that there are limits on the language capacity of the right hemisphere of adult man. The right hemisphere is unable to relate subject to object via a verb, to respond to verb commands [6] or to comprehend the semantic aspects of verbs. It is skilled mainly at attaching noun labels to pictures and objects. Yet, the ability to tell the negative from the positive would seemingly imply an understanding of "doing" versus "not doing" something, and hence some comprehension of verbs. It may be, however, that the "notness" is associated with the entire semantic complex and thus the minor hemisphere may follow a different set of principles in analyzing the positive–negative dimension than the major.

The extent and nature of verbal structure processing in the right hemisphere remain unknown, but it conceivably has become locked in an infantile mode, wherein only si mple naming is possible and "no" is the most deeply entrenched concept. These two aspectscmay be among the most elementary components of logic and/or language, both ontogenetially and perhaps phylogenetically.

The present studies do not support the contention that the right hemisphere is capable of producing speech [7, 8, 9]. The observation that the younger patients could verbally identify visual patterns in the left visual field is better explained by alternative hypotheses. In the case where one of four numbers was identified when flashed to the right hemisphere, all indications are that an interhemispheric cross-cueing strategy was being used. This interpretation is consistent with the RT data, the subject's report, and the disruption caused by forcing a rapid response. The nature of the cross-cueing process may include the following steps: The left hemisphere counts, emitting sub-vocal signals that transfer to the right hemisphere, intra- or extracranially; the right hemisphere comprehends the sub-vocal signals and when the stimulus number is reached the right hemisphere signals the left to stop and respond. It seems improbable that a right hemisphere speech system would require a proportionately greater time to identify larger numbers and yet be capable of making prompt responses to a set of two known alternatives. Further studies should reveal how large a set of stimulus alternatives (not necessarily numerical) could be promptly dentified verbally without using an elaborate cross-cueing strategy.

The mechanism for prompt verbal recognitions in the two-choice situation is more difficult to ascertain. Three major interpretations may be entertained, some of which are imade less tenable by the RT findings. The least likely possibility is that this stimulus situation provokes verbal output from the right hemisphere; in that case the 200 msec delay for left visual field stimuli must reflect either a slower visual recognition ability, which is inconsistent with the motor RT data (see below), or else a slower speech emission system. In addition to being more sluggish, this hypothetical speech system would be greatly slowed or even inoperative unless a limited number of known stimulus alternatives were available. Nonetheless, this possibility cannot be completely ruled out.

A second possibility is interhemispheric cross-cueing, whereby the right hemisphere performs the two choice discrimination and sends an "either–or" recognition pulse (either subcortically or extracranially) to the left hemisphere. The additional time required for recognition of the transferred "pulse" could easily fit within 175–200 msec. This interpretation accounts for the excessive delays in the multiple stimulus situation, since communication of several alternatives cannot be encoded in a single "bit" of transferred neural information. Earlier studies on the somatosensory system [6] demonstrated that if the slightest clue was available to the left hemisphere, a verbal distinction could be made between two known quantities presented to the left side of the body.

A third mechanism which would permit these prompt number recognitions in the left visual field is the subcortical transfer of rudimentary pattern information to the left hemisphere, perhaps at midbrain levels. The cortical visual system is known to perform a "feature analysis" upon patterned light, and some elementary stimulus features representing pattern information may be encoded bilaterally at lower levels. If the left hemisphere knew what the stimulus alternatives were, but not otherwise, the whole pattern could then be inferred from the limited features available to it. Subject L.B., in fact, volunteered that he could see "two bars" in the "0" stimulus, which sufficed to distinguish it from the "1".

A mechanism involving neural transmission or processing rather than a subtle motor cross-cueing strategy is also suggested by the fact that only the youngest patients were capable of talking about patterns in their left visual fields. One of them had had extensive practice on this type of task and the other had but little, yet adult patients of equivalent experience and motivation failed completely. The neural plasticity presumably associated with youth could enable these split-brain patients to develop pathways for making enough lateralized visual stimulus infomation available to the contralateral hemisphere to solve such problems.

Recently, a series of reports has suggested that the right hemisphere is capable of simple speech. BUTLER and NORSELL [8] and TREVARTHEN [7] have asserted that these patients can describe pictures of simple objects presented to the right hemisphere. The problems of interpreting these studies have been discussed extensively elsewhere [6], and, in general, simple cross-cueing strategies can account for the results to date.

A report by MILNER and TAYLOR [9] also can be interpreted as a demonstration of right hemisphere speech, but a better account is given by the hypotheses based upon the present findings. In tests of somatosensory function, patients could successfully perform a standard two-point discrimination using the left hand. Such a task, however, involves an essentially "digital" response on the patient's part and could easily be solved by cross-cueing or transfer mechanisms of the type described.

When discriminative motor rather than verbal responses were made, RT's were fastest when the stimulus fell in the visual half-field ipsilateral to the hand in use. Moreover, the two hemispheres were equivalent in RT when flashed while their contralateral hand was in use, indicating that there are no substantial differences here between hemispheres in discriminative capacity or in attaching sensory decisions to motor output. When the right (dominant) hand was in use, however, RT's were significantly slower to flashes delivered to the ipsilateral hemisphere than when the left hand was active. This marked impairment of visuomotor integration in the right hand–right hemisphere combination has been observed in other contexts [10, 6] and may be a manifestation of attentional shifts between the hemispheres as a function of hand usage. Accordingly, when the hand preferred by the dominant hemisphere is acting, there may be an asymmetrical reduction in the ability of the right hemisphere to process information.

The relative delay of the crossed hand–field combinations was also described by JEEVES [11] as ranging between 17 and 60 msec, using unpatterned visual stimuli with acallosal patients. In order for the stimulated hemisphere to thus govern its ipsilateral hand, there must either be a transfer of the visual information to the opposite motor cortex, a cross-cueing strategy [6], or a direct engagement of extra-pyramidal or other uncrossed motor pathways. The current verbal and motor RT data make the last alternative most acceptable. Cross-cueing is deemed unlikely in this instance because the interhemispheric delays would seem too short (12–60 msec) to permit a cueing response to be emitted and detected. Interhemispheric transfer of visual pattern or "press–no press" information seems equally improbable, because if it can occur with a delay of 12–60 msec, then the left hemisphere also should have left visual field information available this quickly in the verbal task; thus, the delays should have been shorter than the 200 msec actually observed. If an interhemispheric transfer explanation is to remain tenable at all, we must assume a peculiarity in the verbal motor system, such that transferred 1–0 information is slower in engaging discriminative verbal responses than is non-transferred (intra-hemispheric) information, and further that this relative delay is much longer than the comparable coupling time between visual information and the simple go–no go motor responses. A final explanation that may rescue the transfer hypothesis is that a verbal response set by the patient focuses the attentional capacity within the left hemisphere more so than does a right hand motor response set, so that reactivity (processing speech) to stimuli projected to the right hemisphere is correspondingly diminished during the verbal task.

It is always a tenuous matter to report on the absence of function, and the question still remains of the nature and extent of language capacity in the minor hemisphere. PREMACK [12] has demonstrated in chimps a much higher level of language ability than had previously been recognized, and his success can be attributed to asking the proper questions of the system and structuring the motivational context appropriately. Indeed, more operational language competence has been shown for the chimp than has been demonstrated in the human right hemisphere. It may well be that more appropriate testing and incentives will reveal a more impressive amount of language or even a qualitatively different form of symbolism in the human right cerebrum. Perhaps, extending the chimp language lesson to severely language impoverished aphasics would reveal a far greater language capability than has been heretofore imagined [13].

Acknowledgement—We thank Mr. WILLIAM GOLDIE of UCSD Medical School for valuable technical assistance.

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Résumé—On a analysé à nouveau les capacités de langage et de parole de l'hemisphère droit chez des sujets à cerveau dédoublé. Les résultats indiquent que l'hemisphère droit ne possède que peu ou pas de capacité syntaxique. La seule dimension sémantique qui ait été comprise par les sujets soumis à une série de test d'appariement image-mot, était la dimension affirmative-negative. En outre, les indications qu'on avait pu avoir antérieurement d'une capacité de parole de l'hémisphère droit n'ont pu être confirmés . Les différences dans le temps de réaction verbale à des stimulus visuels projetés aux hémisphères droit et gauche étaient interprétés, ou bien comme les conséquences de mécanismes de transfert sous-corticaux, ou bien comme résultant de stratégies par reperes croisés.

Zusammenfassung—Die Leistungsfähigkeit der rechten Hemisphäre hinsichtlich Sprach und Sprechvermögens wurde bei Patienten mit Balkendurchtrennung analysiert. Die Ergebnisse zeigten, daß die rechte Hemisphäre nicht imstande ist, syntaktische Sprachleistungen zu gewädnrleisten. Nur hinsichtlich der semantischen Dimension schien diese These nicht zu stimmen, da in einer Serie von Bildprüfungen Verstädnnis gezeigt wurde. Trotzdem konnte ein weiterer Hinweis auf rechtshemisphärische Sprechfähigkeit nicht gefunden werden. Die Differenz zwischen Sprechreaktion und optisch dargebotenen Reiszen—bezogen auf die rechte und die linke Hemisphäre—wurde entweder als Folge eines subkortikalen Übertragunsmechanismus' oder als Kreuzungseffekt interpretiert.