D-89

Neuropsychologia, 1973, Vol. 11, pp. 443 to 450. Pergamon Press. Printed in England.

ORIENTATION TO PICTORIAL NOVELTY BY SPEECH-DISORDERED CHILDREN

NORMAN H. MACKWORTH*, NETTA W. GRANDSTAFF and KARL H. PRIBRAM

Stanford University, California, U.S.A.

Abstract—The Mackworth wide-angle reflection eye camera was used to record the position of the gaze on a display of 16 white symbols. One of these symbols changed to red after 30 sec, remained red for a minute of testing, and then became white again. Ten aphasic children (aged 5–9) were compared with 10 normal children matched for sex and age. The normal children looked immediately at the red circle, and then began to look away. The 3 aphasics with low verbal I.Q., but high nonverbal I.Q., stared at the red circle for the whole minute. These 3 children with high nonverbal I.Q.s were markedly different from the children with low non-verbal I.Q.s. The 7 less severe cases showed poor visual orientation, being slow to look at the novel item, and often looking away from the display. Prolonged staring at novelty appears to be related to more serious problems specifically involving speech and suggests a difficulty in forming an internal model, while generalized failure of visual orientation to external novelty appears to be related to low I.Q. as a whole.

INTRODUCTION

EFFECTIVE perception depends on the formation of a series of neural models of the environment [1,2]. An item can only be recognized when it is matched with a previously recorded model of a similar or identical item. These models include predictions about future events. Incoming stimuli are compared with the expected event. The orienting response appears when there is a mismatch between the prediction and the actual event [3]. The orienting response habituates or dies away as the neural model is updated to give a more accurate prediction. In the human, the direction of the gaze and its relation to the items in the environment is one of the best measures of the orienting response.

The predictive indications we can obtain from the visual orienting response are important features of gaze recording, especially as so much of language comprehension depends on the ability to make accurate predictions at high speed. People seldom look without looking forward. As MACKWORTH and BAGSHAW [4] put the matter, the line of sight is not only probing where the action is, it is also probing where the action might be, as suggested by the context of the occasion. The gaze then becomes a direct agent of thought, and not just a plaything at the mercy of any shifting stimulus. The line of sight is actively seeking out informative areas, and these forward-looking actions are the expression of on-going predictions about the location of the most likely sources of important information. The role of internal model becomes clear in at least one respect. People are continuously extrapolating from their expectations and these predictions take the form of internal neural representations selected as being similar to the next most likely input. Normally people are also checking their beliefs against reality by comparing their internal patterns with the new input coming from external visual stimuli. Ordinarily, therefore, attention can begin internally before stimuli impinge on the sense organs, this being true for both adults and children.

Lesioned monkeys have been examined by eye camera methods by BAGSHAW, MACKWORTH and PRIBRAM [5, 6]. Bilateral removal of the amygdaloid regions in the monkeys give quite a different effect from that produced by bilateral removal of the inferotemporal regions. Amygdalectomy completely abolished the customary visual orienting responses of normal monkeys: they no longer peered out of their viewing peephole at the matrix of 16 symbols. This was quite different from the curiosity exhibited by normal monkeys. Resections of the inferotemporal (IT) cortex however produced yet another kind of change in their visual orienting responses. These monkeys had an increased number of visual orienting responses compared to normal. This overorienting was not effective however. Not only were there more instances of looking at the matrix, but there were also more instances of looking off the stimulus display as well. The main effect of the inferotemporal damage was that the monkeys with inferotemporal lesions had difficulty in learning the distinctive features in a display that were being accompanied by a reward. They found it more difficult than normals, and indeed made no progress at all in learning to look at the rewarded numeral 8 and to disregard the unrewarded numeral 3.

The measurement of the direction of the gaze is also one of the easiest ways to record orientation in children. The normal child very quickly detects an unexpected change in his environment, and stares at the new item until he has identified it or has lost interest. The duration of the visual orientation response gives a measure of the time needed to construct an internal model of the novel event: this is because the time spent looking at the novel item depends partly on the speed of the internal processing of the visual stimuli. Rapid finding of the key item of novelty and brief study of that item normally go together. But as we shall see later, certain cognitive difficulties in children lengthen the time spent looking at the novelty without delaying their rapid acquisition of that item. Other difficulties, especially those of retardate children, are characterized by the children spending less (rather than more) time than normal on the highly informative areas in pictorial displays [7, 8]. Such retardate children may have difficulty in realizing which details are important, as in puzzle pictures, or they may have trouble in processing peripherally presented information. Certainly, the ability to deal with more than one thing at a time seems to be a function of cognitive growth [9].

The general approach in our own studies of the speech disordered children was to try to discover whether such children had any signs of difficulty in orienting to a novel stimulus: were they either slow to find the novelty or did they spend more or less than the usual amount of time looking at it. The work of BAY [10] on adult aphasia and conceptual thinking would suggest considerable difficulties in categorization processes. Similarly SCHUELL, JENKINS and CARROLL [11] find that recognition of stimulus equivalence is important in understanding adult aphasia. These authors found a common factor across a huge range of different situations since "stimulus equivalence" included (1) printed letter matching, (2) pointing to a pictured object when reading its printed name, (3) hearing its spoken name, or even (4) explaining proverbs. (Here the pulling out of universals, implied by the idea of stimulus equivalence, essentially requires the recognition of the equivalence between common situations and experiences.) There is therefore good reason to search for a more basic difficulty which could underlie such evidence of disturbed abilities.

METHOD

The general method we used was to present very simple pictorial material in our efforts to discover whether children who were attending an aphasia clinic had measurable nonverbal difficulties in addition to their more obvious verbal difficulties. The children were instructed as follows: "We would like you to look at these pictures" and the displays of 16 white geometric shapes were then demonstrated to them. After these items had been displayed 10 times, one of the items suddenly changed to a red color. From earlier work with normal children, we knew that even 2-year-olds will immediately stare at the red circle, and then after a very few trials look away from it. Age did not seem to have any effect at all on this simple process, since it had no influence on the time to find the novelty initially, nor on the time to look away from the item. This work by MACKWORTH and OTTO [12] on normal children was repeated by MACKWORTH and BAGSHAW [4] on normal monkeys. The results were surprisingly similar and indeed were virtually identical, again suggesting that we were dealing with a very basic behavioral response. The normal monkeys immediately picked out the novel item and soon lost interest after about 15 trials, just like the normal children.

Subjects

Ten children attending for therapy were tested at the Scottish Rite Institute of Childhood Aphasia associated with Stanford University Medical School. All the children were between the ages of 5 and 9 years of age. In view of the considerable difficulties in classifying such children, we have given some brief clinical details in the Appendix on each case. The main point is that not only were they suffering from a wide variety of language handicaps, but they suffered from quite different degrees of impairment in speech comprehension. These children were matched with a normal group on the basis of age and sex. There were 5 boys and 5 girls in each group.

Apparatus and test procedure

The Wide Angle Reflection Eye Camera was used to record where the children were looking on the display [13]. With this device the child simply rests his chin and forehead against supports. There is no bite bar involved. The display consisted of a 4 $\times$ 4 matrix of white geometric symbols on a black background. It was presented for 10 successive 3-sec trials, separated by 5 sec between each trial. Then, without any obvious break in the series of presentations, the novel symbol was introduced: one circle unexpectedly appeared as red, all the other symbols remaining white. The test circle remained red for 20 trials and then changed back to white for the final 10 trials, which were therefore the same as the first 10 trials.

A motion picture record of the child's pupil was made while he was looking at the display. The record showed a reflection of the display in the child's pupil. The stimulus item in the centre of the pupil was the one that the child was looking at [4]. More than 8000 readings were taken in this study.

Scoring

The main measure was the time that each child spent looking at the test circle, both when it was white and when it was red. Less than 5 per cent of the frames were discarded as being unreadable. The percentage of time that the child looked off the matrix was also calculated.

RESULTS

The aphasics as a group showed less habituation than the normal children. Table 1 and Fig. 1 show that the normal children spent about 50 per cent of total time looking at the red circle during its first appearance, but only 17 per cent in the last five of the 20 trials, a difference of about 33 per cent. For the aphasic group as a whole, this difference was only about 9 per cent. Inspection of the data for the aphasic children suggested that they might be separated into two groups on the basis of the ratios of their verbal and nonverbal I.Q.

scores (See Appendix). The three children with the lowest ratios had quite high nonverbal I.Q.s. They had severe impairment of verbal comprehension [14]. The others mostly had fairly low nonverbal I.Q.s and were therefore mildly retarded. Their main difficulty lay in expression. The *severe* group had verbal to nonverbal ratios of 0·58 to 0·74, while the *mild* cases showed ratios ranging from 0·80 to 1·18.

Severe aphasics show failure of habituation

The three children with severe difficulties in speech comprehension oriented strongly to the red circle as soon as it appeared, and, in contrast to the other children, they showed almost no tendency to habituation. They continued to stare at the red circle during the last ten trials. The difference between the normal and aphasic children in the amount of habituation was significant ($p<0{\cdot}02$).

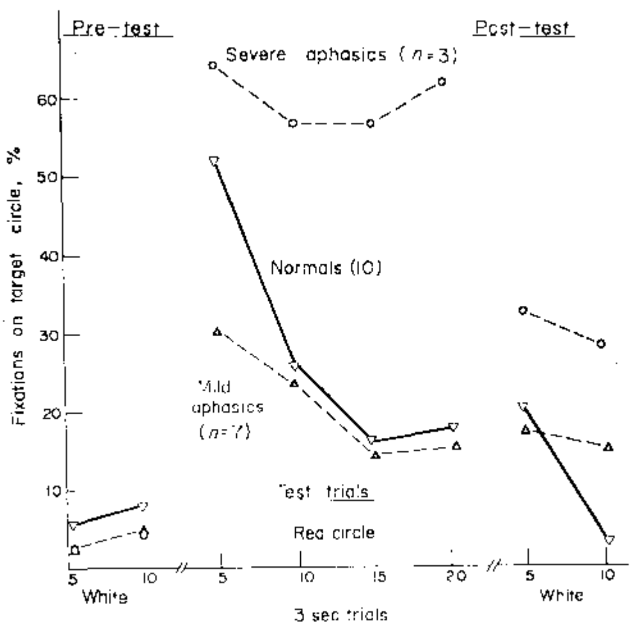

FIG. 1. The percentage of time that normal and aphasic children looked at a certain circle in a display of 16 white geometric symbols. The circle was white in the pre- and post-test trials, but red during the test trials. Each trial lasted 3 sec.

Table 1. Time spent looking at red circle, as a percentage of total looking time

Group	Successive blocks of five 3-sec trials 1–5	6–10	11–15	16–20	Habituation Difference between first and last block
Severe aphasics ($n=3$)	63	56	56	61	2
Normals ($n=3$)	47	15	14	16	31
Difference	16	41*	42*	45*	
Mild aphasics ($n=7$)	30	23	13	14	16
Normals ($n=7$)	53	34	19	19	34
Difference	—23*	—11*	—6	—5	

* Significant at $p<0{\cdot}02$, with a two-tailed test.

Mild aphasics show reduced orientation

The children with smaller difference between verbal and nonverbal I.Q.s were initially slow to notice the appearance of the red circle. These mild cases spent significantly less time on the red circle during the first block of five trials than did the seven matched normal children ($p<0{\cdot}02$).

Off-matrix looking time

Orienting to the red circle necessarily involves looking at the display. Therefore a study was made of the time that the children spent looking off the display. Table 2 shows that the *Severe* group spent *less* time looking off the display than did the normals ($p<0{\cdot}001$). The *Mild* cases spent significantly *more* time looking off the display than did the matched normals ($p<0{\cdot}001$).

Table 2. Percentage of time spent looking off symbol matrix during red circle phase

Group	Blocks of 3-sec trials 1–5	6–10	11–15	16–20	Means
Severe aphasics ($n=3$)	2	4	0*	8	4*
Normals ($n=10$)	4	7	13	11	9
Mild aphasics ($n=7$)	8	25*	21*	12	17*

* Significantly different from normals ($p<0{\cdot}001$).

Relation between nonverbal I.Q. and orientation scores

The aphasic *S*s were ranked according to the time that they spent looking at the red circle during the first five trials that it was on view. The five *S*s who spent least time on the red circle had a mean nonverbal I.Q. of 89, while the other five had a mean nonverbal I.Q. of 111. The difference between these two mean I.Q.s was significant ($p<0{\cdot}05$ on a one-tailed Mann–Whitney U-test for very small samples [15]). The verbal I.Q.s showed no significant difference between the two groups. Both sets were almost equally low.

DISCUSSION

The *severe aphasics* showed good orientation but did not habituate. They continued to stare at the test circle as long as it remained red. These children showed a marked discrepancy between their verbal and nonverbal I.Q. Their very poor verbal comprehension might be partly related to their deafness, but clearly there was a more fundamental defect, such as constructing an internal model at all in the time allotted. Perhaps this difficulty stems from a difficulty in naming the display. Comprehension of speech requires the high speed of coding of the articulatory system [16]. Interference with this process must inevitably cause serious interference with comprehension.

The *mild aphasics*, who had less difference between verbal and nonverbal I.Q.s, showed a deficiency in orienting. They were slow to notice the change of the circle to red, and they also showed a marked tendency to look away from the display, reminiscent of monkeys with amygdala lesions. They suffered from a failure of attention, in marked contrast with the severe cases, who remained glued to the red circle. Spitz [17] pointed out that retardates may take longer to record a stimulus and longer to react to it or code it. He later [18] reported that retardates are very much slower than normals at finding jigsaw puzzle pieces that were distinguished only by shape. Such behavior may result from a reduced orienting response, similar to that found with mild aphasics, many of whom had low nonverbal I.Q.s.

VINOGRADOVA [19] has discussed a dichotomy similar to that found in the present study in simple orienting tasks analyzed by EEG, galvanic skin response and vascular changes [20, 21]. Patients with cerebral damage showed a powerful and prolonged orienting response. She suggested that this was due to the release of the subcortex from the inhibiting effect of the cortex. (Our monkeys with inferotemporal lesions showed tendency in this direction.) Vinogradova further reported that some mental defectives had a weak or absent orienting response much as that found in the mild aphasic group of retardates by us.

CONCLUSIONS

1. By recording the eye movements of aphasic children while they were watching a simple geometric display, it has been found that this very heterogeneous group of children with speech disorders showed a slower habituation to novelty than did normal children.

2. The severity of the condition was assessed by determining the extent to which the verbal I.Q. score for the individual child fell below his nonverbal score. When the children were rank ordered on this basis, they could be divided into two groups. These two groups behaved quite differently in the Red Circle Test.

3. The *severe aphasics* had low verbal I.Q. scores, but high nonverbal I.Q. scores. These children showed immediate and prolonged orientation to a novel stimulus, with almost no habituation. We suggest that this failure to habituate was due to difficulty in forming an internal mental model of the novel event in the external environment.

4. The *mild aphasics* had less difference between verbal and nonverbal I.Q. scores. In most cases the nonverbal I.Q.s were quite low. These children were slower than normal to notice the novel stimulus; such behavior is characteristic of the mildly retarded child.

5. The eye camera approach, using simple pictorial displays, seems to have a place in further research to discover whether severe speech disorder is accompanied by a selective defect in internal model building, in contrast to milder problems, associated with mild retardation.

Acknowledgements—N. H. Mackworth was supported by Research Scientist Award K5-36, 477 from the National Institute of Mental Health. K. H. Pribram was supported by Research Career Award K6-15, 214, also from NIMH. Other support came from NIMH Grants MH 12970 and MH 8304. We thank Dr. Muriel Bagshaw and Professor J. Eisenson of the Stanford University School of Medicine for much advice and help. Dr. Jane Mackworth assisted in the preparation of the manuscript.

REFERENCES

1. PRIBRAM, K. H. The Four R's of Remembering. In *On the Biology of Learning*, K. H. PRIBRAM (Editor) pp. 191–225, 1969. Harcourt Brace and World, New York.
2. PRIBRAM, K. H. *Languages of the Brain*. Prentice-Hall, Englewood Cliffs, New Jersey, 1971.
3. SOKOLOV, E. N. Neuronal models and the orienting reflex. In *Brain and Behaviour 2. Perception and Action: Selected Readings*, K. H. PRIBRAM (Editor), pp. 225–234, 1969. Penguin Books, Baltimore.
4. MACKWORTH, N. H. and BAGSHAW, M. H. Eye catching in adults, children, and monkeys: some experiments on orienting and observing responses. Annual Meeting, 1968, *Proceedings of Association for Research in Nervous and Mental Diseases*, 48; Chapter 14 In *Perception and its Disorders*, D. HAMBURG, K. H. PRIBRAM and A. J. STUNKARD (Editors), pp. 201–213. Williams and Wilkins Co., Baltimore, 1970.
5. BAGSHAW, M. H., MACKWORTH, N. H. and PRIBRAM, K. H. The effect of inferotemporal cortex ablations on eye movements of monkeys during discrimination training. *Int. J. Neurosci.* **1**, 153–158, 1970.
6. BAGSHAW, M. H., MACKWORTH, N. H. and PRIBRAM, K. H. The effect of resections of the inferotemporal cortex or the amygdala on visual orienting and habituation. *Neuropsychologia* **10**, 153–162, 1972.

7. WILTON, K. M. and BOERSMA, F. J. *Eye Movements, Surprise Reactions and Cognitive Development.* Rotterdam University Press (In Press).
8. MUIR, W. Looking behavior in normal and retarded children during directed search tasks and discrimination learning. Unpublished Ph.D. Thesis, University of Edmonton, Alberta, 1971.
9. VURPILLOT, E. The development of scanning strategies and their relation to visual differentiation. *J. exp. Child Psychol.* **6**, 632–650, 1968.
10. BAY, E. Aphasia and conceptual thinking. In *Problems of Dynamic Neurology*, L. HALPERN (Editor), pp. 1–12. Hebrew University, Jerusalem, 1963.
11. SCHUELL, H. M., JENKINS, J. J. and CARROLL, J. B. A factor analysis of the Minnesota test for differential diagnosis of aphasia. *J. Speech Hear. Res.* **5**, 349–369, 1962.
12. MACKWORTH, N. H. and OTTO, D. A. Habituation of the visual orienting response in young children. *Percept. & Psychophys.* **7**, 173–178, 1970.
13. MACKWORTH, N. H. The wide angle reflection eye camera for visual choice and pupil size. *Percept. & Psychophys.* **3**, 32–32, 1968.
14. WARRINGTON, E. K. The incidence of verbal disability associated with reading retardation. *Neuropsychologia* **5**, 175–179, 1967.
15. SIEGAL, S. *Non-parametric Statistics for the Behavioral Sciences*. McGraw-Hill Books, New York, 1956.
16. LIBERMAN, A. M., COOPER, F. S., SHANKWEILER, D. P. and STUDDERT-KENNEDY, M. Perception of the speech code. *Psychol. Rev.* **74**, 431–461, 1967.
17. SPITZ, H. H. Field theory in mental deficiency. In *Handbook of Mental Deficiency*, N. R. ELLIS (Editor), pp. 11–40. McGraw-Hill, New York, 1963.
18. SPITZ, H. H. Effects of stimulus information reduction on the search time of retarded adolescents and normal children. *J. exp. Psychol.* **82**, 482–487, 1969.
19. VINOGRADOVA, O. S. The orientation reaction and its neurophysiological mechanisms. *Acadm. Ped. Sciences. R.S.F.S.H.* Moscow, 1961. (See Lynn, R. 1966, and Dunn and Kirk, 1963.)
20. DUNN, L. M. and KIRK, S. A. Impressions of Soviet psycho-educational service and research in mental retardation. *Except. Child.* **29**, 299–312, 1963.
21. LYNN, R. *Attention, Arousal, and the Orientation Reaction.* Pergamon Press, New York, 1966.

APPENDIX

CLINICAL DATA ON APHASIC CHILDREN RANKED ACCORDING TO I.Q. RATIOS

Age	EEG	Verbal/nonverbal I.Q. (Ratio)	Comprehension	Expression
8	None	124/105 (1·18)	No language problems remaining now, after extensive therapy.	Mild difficulties. Confuses b–p, g–d in reading.
9	Abnormal	69/69 (1·00)	Quite good for most situations.	Conveys thoughts well in shorthand speech like young child.
7	Normal	81/88 (0·92)	Fairly good, but some errors like paddle for puddle. Confused by complicated directions. Real difficulties. Lacks some words, e.g. insect, weapon.	Rarely speaks. Often difficult to follow his elliptic, eccentric and cryptic replies. Poor articulation.
9	Abnormal	71/79 (0·90)	Difficulty in following directions and in sequencing.	Avoids complex grammatical forms. Below normal.
5	Abnormal	77/95 (0·81)	Good except for more complex sentences.	Good.
9	Normal	70/87 (0·81)	Deaf; eventually able to answer "where" and "what" questions about pictures of concrete situations. Language understanding needs expansion. Tries hard.	Unable to talk spontaneously, but gives 2–3 word answers to questions. Considerable limit in functional expression.
7	Abnormal	93/117 (0·80)	Like adult with mild dysphasia. Inability to understand things. Receptive vocabulary average to low. Trouble with main ideas and with long and complex directions.	Reluctant to verbalize. Incomplete sentences. Word finding difficulties. Reads well.

Age	EEG	Verbal/non-verbal I.Q. (Ratio)	Comprehension	Expression
			Severe Group	
6	Abnormal	83/111 (0·74)	Retarded language concepts. Limited speech understanding. Many confusions, e.g. mine/yours. Memory sequencing difficulties.	Stutters. Facial twitch. General drift of talk easy to follow. Poor articulation.
7	Normal	70/124 (0·58)	Deaf; poor understanding of instructions. Brief staring episodes lasting 10 sec from which easily aroused.	Does not often utter intelligible expression. Vocabulary fair.
9	Abnormal	73/127 (0·58)	Deaf; poor comprehension. Fails to remember 4 words in series. Gives inappropriate answers. Repeats words. Replies by free association. Good abstract thinker. Keen visual attention. High artistic ability.	Poor. "Guess what I have?" becomes "What guess I have?" Utters incomplete phrases and isolated words. Cannot imitate polysyllable words. Articulation good.

Résumé—On a utilisé la caméra à réflection oculaire à large angle de MACKWORTH pour enregistrer la position du regard à la présentation de 16 symboles blancs. Un de ces symboles passait au rouge après 30 secondes, restait rouge pour une minute puis redevenait blanc de nouveau. Dix enfants aphasiques (âge 5–9) étaient comparés à 10 enfants normaux appariés pour le sexe et l'âge. Les enfants normaux regardaient immédiatement le cercle rouge puis commencaient à en détourner le regard. Les trois aphasiques avec bas Q.I. verbal mais avec Q.I. non verbal élevé fixaient le cercle rouge pendant toute la minute. Ces trois enfants avec Q.I. non-verbal élevé étaient très différents des enfants avec Q.I. non-verbal bas. Dans les 7 cas moins sévères l'orientation visuelle était mauvaise, les enfants étaient lents à regarder le nouvel item et souvent le regard s'écartait du tableau de présentation. La fixation prolongée sur l'objet nouveau apparaît être relation avec des problèmes plus graves impliquant spécifiquement le langage; ce comportement pourrait tradine une difficulté à constituer un modèle interne tandis qu'un échec total de l'orientation visuelle à la nouveauté extérieure apparaît être en relation avec un Q.I. total bas.

Zusammenfassung—Die Mackworth Weitwinkel-Reflektion-Augenkamera wurde benutzt, um die Blickrichtung auf ein Arrangement von 16 weissen Symbolen festzuhalten. Eines dieser Symbole veränderte sich zu rot nach 30 Sekunden, blieb eine Minute hindurch rot, und wurde dann wieder weiss. Zehn fünf bis neunjährige asphasische Kinder wurden mit 10 normalen Kindern gleichen Alters verglichen. Die normalen Kinder sahen sofort nach dem roten Kreis und begannen dann fortzusehen. Die drei asphasischen Kinder mit der niedrigsten verbalen Intelligenz, aber mit hoher nichtverbaler Intelligenz starrten eine volle Minute auf den roten Kreis. Diese drei Kinder mit hoher nichtverbaler Intelligenz waren sehr verschieden von den Kindern mit hiedriger nicht verbaler Intelligenz. In den sieben weniger ernsten Fällen zeigte sich schlecthe visuelle Orientierung. Diese Kinder brauchten lange Zeit, bis sie nach dem weissen Reiz blickten, und sahen oft von dem Arrangement fort. Langes Starren auf Neues scheint mit ernsten Sprachproblemen zusammenzuhängen, und es scheint, dass hier eine Schwierigkeit vorliegt, innere Vorlagen zu entwickeln, während allgemeines Versagen der visuellen Orientierung auf neue Reize mit totaler niedriger Intelligenz zusammenzuhängen scheint.