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Visual Reading and Cross-Modal Transfer of Learning in Congenitally Blind Humans with Residual Light Projection'

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Abstract Hunstad, E. 1985. Visual Reading and Cross-Modal Transfer of Learning in Congenitally Blind Humans with Residual Light Projection. *Scandinavian Journal of Educational Research 29,* 17-41. Visualized braille was presented on Closed Circuit Television (CCTV) to six subjects, 12-50 years of age. All subjects were established tactile readers of braille. Pretest for reading visual braille showed that the subjects spontaneously recognized and read this kind of text. Thus, the results support cross-modal transfer of learning from tactile to visual modality. Reading performance from pre- and post-test in visual braille was compared with that in tactile braille. Moreover, aftet six days of intensively visual training with geometrical figures and ordinary print, the post-tests showed that these blind subjects could discriminate visual forms and read ordinary print by use of CCTV. In this paper the discussion is restricted to the results concerning visual and tactile braille testing.

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Introduction

Cross-modal transfer as a factor in perceptual learning was first pointed out in the letter of Molyneux (1689) to John Locke:

> Suppose a man born blind, and now adult, and taught by his touch to distinguish between a cube and a sphere of the same metal. Suppose then the cube and sphere were placed on a table, and the blind man made to see: query, whether by his sight, before he touched them, could he distinguish and tell which was the globe and which the cube? ... The acute and judicious propose answers: not. (Gibson l969, p.216).

Post-operative studies (Gregory & Wallace 1963; Umezu, Toni & Uemura 1975; von Senden 1960) of subjects with congenital cataract or keratitis have attempted to determine what congenitally blind adults who achieve their sight after a successful eye operation can see, and to what extent previous tactile learning transfers to the visual modality. Recent reports (Ackroyd, Humphrey & Warringston 1974; london 1960; Valvo 1968) partially confirm von Senden's (1960) results on cross-modal transfer of learning. According to Hatwell (1 978), however; only one single example of cross-modal transfer of learning is to be found (Gregory & Wallace 1963). Having been without sight from the age of about ten months, the patient's sight was restored through a successful corneal graft in his early fifties. Post-operative observations showed that the patient could identify all capital letters visually without training, but not the lower-case letters. He had previously learned capital letters and numbers in relief through touch. When colour vision was tested (Ishihara), all the numbers were correctly read. In a critical discussion, Gibson (1969, p.216) points out that 'though one cannot draw conclusions from this case about the nature of very early visual development, there are interesting observations on cross-modal transfer'. According to the nativist view that the various modes of sensory experience are separate and specific for each sense modality, any intermodal similarity must be a result of interpretation through association. Cross-modal transfer in the example of Gregory & Wallace (1963) is accordingly interpreted as the result of associations which built up between sight and touch during early infancy, before sight was lost. These associations must be non-specific since letters and numbers had not been learned at that age. Verbal mediation might possibly be involved. For Gibson (1969) this explanation seems rather strained, because with her empiricist viewpoint she asserts that perceptual learning through one sense can give cross-modal transfer to another modality.

In a previous investigation (Hunstad, Selnes & Krekling 1979) no cross-modal transfer of learning was registered, either from the tactile to the visual modality or vice versa. Nevertheless, the present author decided to undertake a further investigation of cross-modal transfer of learning, **i.~** whether or not the use of an electronic magnification device (CCTV) with subjects having congenital amaurosis/light projection would give equally favourable conditions as compared with post-operative investigations of patients with congenital cataract/congenital keratitis. The possibility may not be excluded since we found (Hunstad, Selnes & Krekling 1979) one subject with vision no better than 0.01 who achieved good visual reading performance with normal print on CCTV (82.7 words/mm. with full comprehension of content). However, there is a real difference in sight quality between vision 0.01 and light projection. A person who is able to project the direction of light may still be using light sources to orient himself. 'Faulty light projection implies lack of retinal localization of the stimulus ... The term light perception indicates that a person can no longer localize the direction of a light source but can tell whether or not a light is on or whether it is daylight or dark' (Faye 1976, p.33). The least measurable visual acuity (detail discrimination) according to traditional test methods is 'counts fingers' ad oculum. Visual acuity of 0.01 should be approximately 20 times visual acuity better than count fingers ad oculum. A person who can no longer distinguish the details of any size test close to the eye may have a visual acuity of hand movements. Light projection (light direction discrimination only) then implies even less visual performance than hand movements.

The primary problems for the experiment reported here (the Bergen experiment) thus became: Is it possible that humans with congenital amaurosis/light projection may achieve functional sight by means of CCTV? If so, would tactile experience offer cross-modal transfer of learning to visual modality?

Method

Subjects

The subjects were selected from a population of blind and visually handicapped (N = 1.441) in the county of Hordaland (Odland 1979). The subjects (N = 6) were selected on the following criteria: Age12-50 years; congenitally blind O.U. with light projection metre on the best eye (should not attain measurable vision, eg. counts fingers ad oculum); no other handicaps; normal intelligence or better no previous use of CCTV; good performance in tactile braille reading.

Data about the subjects were based on the archives of the eye clinic (Haukeland Hospital). Subsequently, the data were controlled by thorough-going medical reexamination, educational testings and interviews. According to international conventions (Faye 1976), light projections had to be tested in eight separate quadrants. The medical reexamination showed that the subjects were congenitally blind with light projection from 2-6 m. For all the subjects the etiology of the blindness was Leber's disease.

Apparatus

CCTV is an electron-optical aid which offers possibilities for sight performance where traditional special optic devices are no longer sufficient. A Swedish version of CCTV Magnilink A3, camera-unit B with hand-held optical head Cl/camera holder; table-stand optic C2, TC-card B (Europa**)** and Philips T1, 18" black/white monitor was used. To measure the speed of tactile identification, a Braillemaster (Hunstad 1982) was used. Brailiemaster is a tachistoscope/ tachistotactometer (or a visual/tactile measuring instrument) with exposure intervals from 0.1 to 10 sec. in steps of 10 msec. For identification of letters and words in visual braille, a stop-watch was used.

The room was darkened except for a reading lamp (40 W) placed 2 m behind the subject.The light was directed away from the subject towards a light-absorbent curtain.

Pre-tests

Tests for visual identification and reading of *braille* on CCTV were constructed. The tests covered single letter; wholewords and continuous passages of text (5 items or sentences). Fig. 1. illustrates the typographical image of the tests.

Take off one of your shoes.

Fig. 1. Illustration of visualized braille, imperative method of continuous text.

Construction of the tests was based on the assumptions (Bakker; Smink & Reitsma 1973; Hermelin & O'Connor 1971; Tobin 1971) that spatial, graphical, phonological and semantic representation is learned over a long period through touch. The test for identification of single letters of visual braille was used also for testing individual optimal parameter-levels on CCTV. The subjects were first shown the letter 'B' in visualized braille with linear magnification 40x, full light intensity/ contrast and inverted text image (white letters on black background). The subjects chose their own reading distance. The investigator did not pose leading questions which could help the subjects to associate the image on the monitor with braille. In addition, no communication between the subjects was allowed until the initial tests for the group as a whole were completed. The subjects did not receive any training in visual reading of continuous text before the pre-test (the imperative method).Graphical punctuation marks were not to be used in identification of letters and words in visual braille.

Visual and Tactile Training

Pre4esting results made it desirable to work out training programmes and follow up post-tests in order to confirm whether or not the subjects could increase their visual performance. As far as is known, no research work has been published concerning visual training effects in persons limited to the light projection area, namely the limitation of the present subjects. Further, tactile learning of e.g.ordinary letters and geometric figures might offer even more confirmation of cross-modal transfer of learning when used under visual conditions in posttests.

The training took place in a course-centre as full-time work over six consecutive days and covered: visual, gross-motoric tasks (identification of light sources indoors and outdoors); fine-motoric training programmes on CCTV (identification of geomeric figures, linedrawings (Ingebrigtsen 1972) and ordinary visual print); fine-motoric tactile training programmes (idenufication of geometrical figures, linedrawings and ordinary print in relief, using among other things, Sewell's drawing paper for the blind and Gilligan's Alphabet in relief). Fig. 2 illustrates an item from the training programmes (Ingebrigtsen 1972).

b1.3

Make the other figure
similar to the first

Fig. 2. Illustration of an item from the training programme.

Text and pictures from ordinary books, newspapers and weeklies, were also used for training purposes on CCTV. Visualized braille was not used for training purposes.

Post-tests

The post-tests were carried out over 3 days immediately after the training course.The interval between the pre- and post4ests was at least one month. An attempt was made to construct the post test for visual braille, continuous text (imperative method) so that it would be equivalent to the pre-test for visual braille, according to the principlesin Dansk LIX (Readability Index) 1970. In addition the passages of text taken as a whole, were 'made alike' in regard to total number of letters, high-frequency words, wordlengths, and pointdensity in the braille cells. The sentences in the pre- and post4est were then independently assessed as 'equally difficult' by two experienced teachers of reading according to the principle used in a previous investigation (Hunstad, Selnes & Krekling 1979). Finally, pre- and post4ests were tried out on 72 pupils (comparison group) in the 3rd and 4th grades of a primary school. For a randomly selected half of the subjects ~ = 36), the tests were presented in the sequence pre-test to post-test (sequence A-B), and for the other half of the subjects (N = 36) in the sequence post4est to pre4est (sequence B-A). For both sequences the time difference between the first test and the second test was about 15 minutes. The results on reading speed are shown in Table I.

Standard deviation for the tests A and B in the sequence A-B was 22.2 and 20.1, respectively.
Standard deviation for the tests A and B in the sequence B-A was 29.6 and 30.4, respectively.
The product moment correlation (equivalence reliability) between the tests A and B in the sequence A-B was .90, and corresponding correlation in the sequence B-A was .92. The reliability of internal consistency (the alfa coefficient) varied from *.85* to .91 for the different tests used in the two sequences.

Table I shows that reading speed of test A in the sequence A-B is almost identifical to that of test

B in the sequence B-A. Furthermore, the reading speed of test A in the sequence B-A was 114.5 words/mm; and of test B in the sequence A-B was 113.7 words/mm. When conditions were alike, no difference between the two tests occurred. Thus, the trial showed that for the pupils in the comparison group the two test designs were of similar degree of difficulty. All subjects, except one, fully

Table I. Reading speed in words/min. for the comparison group (N 72).

Test sequence	Reading speed A	B	$\bar{X}$
A - B	110.9	113.7	112.3
B - A	114.5	111.8	113.2
$\bar{X}$	112.7	112.7	112.7

comprehended the texts. Independent of the sequence the mean error frequency for the pre- and post4est was 2.2% and 2.1%, respectively, rating from 0 to 28.9%. With the exception of one subject, no dyslectic symptoms were observed. Both for pre- and post4est in visual braille the wholewords were selected from an investigation of high-frequency words in the Norwegian language (Heggstad 1971). Different words from the collection *(325* words) were used for respectively pre- and post4est. Generally, the test procedure for the measurement of identification and reading speed followed the procedure of our earlier investigation **(**Hunstad, Selnes & Krekling 1979).

Control Tests with Tactile Braille
In order to compare visual and tactile braille reading, control tests for single letters, whole words and continuous passages of text wer constructed in tactile braille These tests were constructed on the same principles as those employed for the tests in visualized braille (Dansk LIX 1970) but were not tried out on visually normal subjects.

Control Groups with Ordinary Print
In order to ascertain if the subjects of the experimental group had reached their maximum reading speed, an investigation using ordinary print on CCTV was undertaken with subjects who had become blind in adult age. According to their sight functioning, the subjects were divided in two control groups in which the subjects had:

1. Light projection 7 cm - 7 metres for one eye and reading vision for the other, or only light projection for both eyes/amaurosis for one,
2. counts fingers from ad oculum to counts fingers < 1 metre, or only counts fingers for both eyes/amaurosis for one.

Previously (or still with one eye) the subjects had common performance in visual reading of ordinary text. Among the subjects having reading vision for one eye, the best eye was occluded during the control measurements. Also the reading speed for the best eye was measured in order to compare the reading ability of the weakest eye with the subjects' general reading capacity. In the control groups a colour monitor was also used.

Results

Pre-tests for Visual Braille
Letter identification. All subjects accomplished sight function with the aid of CCTV already at the stage of the trial of the pre-test. The subjects spontaneously reported that there were two luminous points on the monitor. To the question 'What is it?' every-one concluded that it was the letter 'B' in braille (some of them having first suggested points of light, lamps, car headlights, etc.). The subjects identified all letters of the braille alphabet in non-alphabetic order. Subsequently individual parameter tests were made. Table II shows speed of identification for single letters, error frequency,

reading distance and individual parameters for the subjects. Mean speed of identification (M) was 9.0 letters/mm. ranging from 1.3 to 35.3 letters/mm. Mean error frequency was 1l.2 to ranging from 0 to 44.4%.

When the subjects were asked to point out each point in the braille cells, it was observed that their eye/hand coordination was poorly developed. Their pointing was haphazard with up to 120 degrees directional error. All subjects, though, learned to point precisely after a maximum of two hours' training.

Word identification. The subjects identified words of one to six letters. As one representative example we take here the group results for word with 3 letters: mean value for speed of identification (M) was 2.7 words/ mm; range of identification speed *1.2-5.9* words/mm; mean value for error frequency 20.6 %; range of error frequency 2.8 - 36.4 %.

Reading performance. Reading performance in continuous text (imperative method) of visualized braille was: mean value for reading speed (M) 2.2 words/mm; Range of reading speed 0.8-5.8 words/mm; mean value for error frequency ll.3 %; range of error frequency 0.9 - 23.4 %. All subjects managed full comprehension of the text. In this text pre-test) the subjects spontaneously identified the graphical punctuation marks (period, comma, question mark). Both for word identification and reading performance the individual parameter levels were approximately the same as those for letter identification (see Table II).

Training Effect for Visual Braille. Post-tests (N = 6)

Letter identification. Group data are shown in Figure 3. The mean differences between pre- and post-test was significant at the 0.04 level (Wilcoxon matched-pairs signed ranks two-tailed test). The mean differences in error frequency between pre- and post-test was not significant (Wilcoxon) but had increased by 1.5%.

Word identification. Data for 34etter words are shown in Fig. 3. Mean value for identification speed in post4est was 3.5 words/mm., ranging from 1.3 to 9.2 words/ min.Error.frequency was reduced by 1.1%.

The mean differences between pre- and post- test were not significant, either for identification speed or for error-frequency (Wilcoxon).

Reading performance. Group data are shown in Fig. 3. Reading performance in conti-nuous text (imperative method) was: mean value for reading speed (M) 3.2 words/ mm; range of identification speed *1.5-8.1* words/mm; mean value for error frequency 9.3%; range of error frequency 0 - 26.3%.

The mean differences in reading speed between pre- and post-test were significant at the 0.03 level (Wilcoxon). The mean differences in error frequency were not significant. All subjects managed full comprehension of the text. No dyslectic symptoms were observed for any error in the text.

Control Tests with Tactile Braille

Letter identification. All subjects identified single letters in 0.1 sec. on the Braillemaster. Potentially faster speeds could not be tested because of the limitation of the apparatus. Maximum acceptable error frequency was *25 %*.

Word identificauon. The mean value of the group for the identification of 3-letter words on the Braillemaster was 0.38 seconds/word with individual range from 0.1 to 0.7 seconds/word. Mean value for error frequency was l8.7 % ranging from l0.0-25.0%.

Reading speed for continuous text (imperative method). Reading speed was measured by means of a stop watch. The group's mean value for reading speed was 90.3 words/mm, ranging from 44.0 to 111.0 words/mm. Mean value for error frequency was 1.1% ranging from 0-6.5 %. All subjects fully comprehended the text. Nor were any dyslectic symptoms observed in the control test for tactile braille.

Visual acuity. Measurements immediately after post-testing showed that visual aquity in the subjects did not change during the training programme.

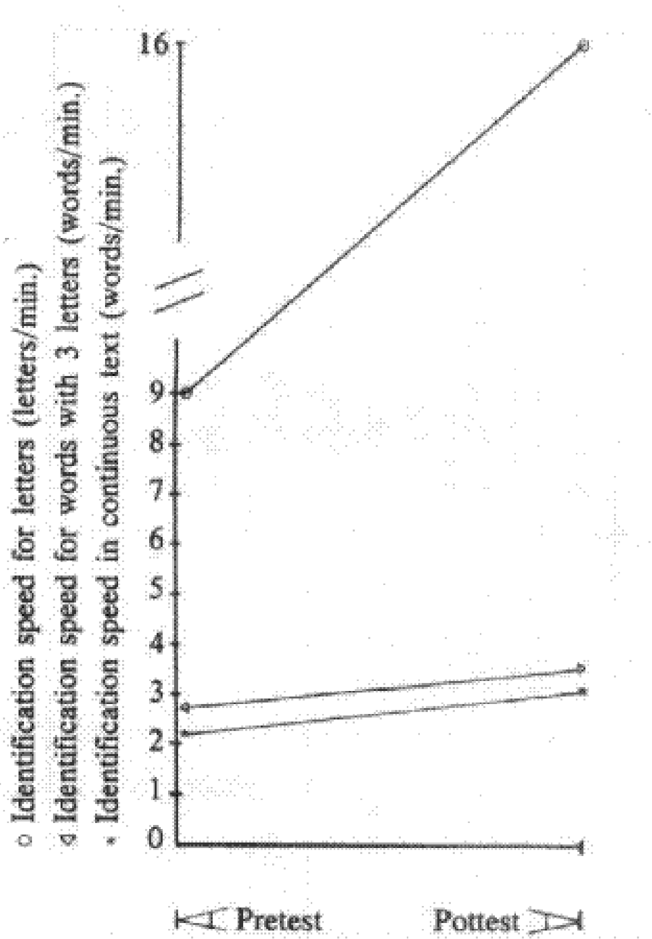

Fig. 3. Pre- and post-tests. Identification speed and reading speed (M) in visualized braille on CCTV (N 6).

Table II. Pre-test. Speed of identification for single letters in visualized braille.

Subjt	Age in years	Identification speed (xTh in letters/mm.	Error frequency in ¾	Range in ident. speed, letters/min.	Reading distance in cm	Prameter level: 1) Linear magnification	Light intensity/contrast	Functioning eye/eyes	Comment
A	42	8.5	2.7	4.6-13.1	7-18	24x	30/30	O.D.	
B	24	35.3	0	23.1-50.0	19-20	33x	30/30	O.S. (O.D.)*	*Preferred OS.
C	50	2.2	0	1.4-5.7	12	l5x	30/30	O.U.**	*Preferred OD.
D	12	1.3	44,4*	0.3-3.7	5-8	24x	30/30		*Memory loss for the form of letters? **Preferred O.D.
E	25	3.7	20.0	1.7-9.7	5-8	28x	20/30	O.U.*	*Preferred OS.
F2)	60	1.6	12.5	0.8-2.6	8-10	24x	30/30	O.S.*	*Discontinued training after three days because of uncorrectable refraction error.
G	17	3.2	0	2.4-10.0	12-15	32x	30/30	O.U.*	*Justihesame

Explanations: 30 = full light intensity/contrast (Maximum of the CCTV) — O.D. = the right eye
0 = minimum light intensity/contrast for a normal eye. — O.S. = the left eye
1) Basic braille cell is equivalent to about 18 points typographic unit. — O.U. = both eyes.
2) Subject F not otherwise included in this paper.

Control Groups with Ordinary Print

In control group I (N = *15)* four of the subjects achieved measurable reading speed for the eye having only light projection. These had mean reading speed of 2.8 words/mm. over the range 1.0 to 5.7 words/mm. All four subjects had been without reading sight for a mean of *23.5* years over the range 15-32 years. Two of those achieved reading performance with red letters against black background only. None of the subjects in group I who had common reading vision for one eye (N = 11) achieved measurable reading ability for the eye with only light projection. In control group 2 (N = 11), all the subjects achieved measurable reading ability for the eye/eyes with counts fingers ad oculum to counts fingers < 1 metre. Mean reading speed was 24.8 words/mm. over the range 10.2 to 73.0 words/mm. The subjects who had only counts fingers with the best eye (N = 5) had been without reading vision for a mean of 9 years over the range 4 to 19 years. This group **(**N = 5) achieved a mean reading speed of 32.5 words/mm., ranging from 10.2 to 73.0 words/mm., or just as good reading ability as the subjects (N = 3) in the same group achieved with the weakest eye, but who had ordinary reading vision for the best one.

Motivation

Both testing and training involved great demands with respect to the subjects' concentration and perseverence. Throughout the whole project the subjects were very cooperative and clearly highly motivated for the tasks.

Discussion

Premises for the Achievement of Sight-Function

Odland (1979) concluded that 'The worst problem for blind people was that they were not able to read' (p. 218).

In the present investigation it became evident that for the subjects it was a deep experience to read their own written language with their eyes. The experience was conceivably all the greater because previously they had never grasped meaning bearing form or attained semantic information from symbols in graphic print images through sight. Even if the reading of visual braille proceeded slowly, a new expectation among the subjects spontaneously and unambiguously came to be expressed through the question: 'Do you think it will be possible to read ordinary written words by this method?' In general, visual braille will hardly become suitable for practical reading purposes. It is significantly more space demanding than ordinary print, also on a CCTV-monitor. This would allow only a low reading speed even for the fully sighted, and the amount of available reading material in braille is very limited. Further, tactile braille cannot be used on CCTV directly, but must be converted to a new, visual print image (Fig. 1).

After six days of intensive visual training, five of the subjects achieved slow visual reading of ordinary print on CCTV. Even though visual reading of ordinary print proceeds slowly in contrast to visual braille, it may be quite suitable for practical reading where the time factor is of low importance, eg. for purposes of consulting works of reference, dictionaries, telephone directories, recipes, instructions, private correspondence, etc. It is important to note in this connection that this kind of reference material is hardly ever available in braille. Visual braille could be used in this investigation, however, as a starting point of sight function among persons with extremely low residual vision and for the testing of possible cross-modal transfer of learning.

The results must be judged against the fact that the subjects had probably never observed anything bearing-meaning with the sense of sight. They were all visual illiterates. In spite of comprehensive opthalmic and pedagogical diagnostic analysis and testing they were unable to achieve any object perception, e.g. counts fingers ad oculum with the best optical correction according to skiascope. According to the medical definitions (The International Association for Prevention of Blindness 1964), the subjects were practically blind. They were also what Barraga (1976) described as legally, educationally and medically blind. All the same, they achieved spontaneous and meaningful sight function in reading visual braille by the aid of CCTV. Even if the identification proceeded quite slowly, and for two of them with a higher error frequency than in tactile braille, it must be maintained that the subjects saw and understood the cues which are necessary for grasping textual content and for object perception. The hypothesis that persons born blind with light projection may achieve sight functions by the aid of electron optics, seems to have been verified.

The selection of subjects seems to assure that they have never had any visual experience in connection with braille. However, it may still be doubted whether conventional opthalmic and pedagogical testing methods actually measured eventual and different sight functions in the practically blind subjects. In the initial interviews of the experiment only two of the subjects conveyed that they perhaps had 'seen something'. Both maintained that the visual impressions had appeared rather seldom, and only in twilight, they believed. One of them had seen white lines on the asphalt in the schoolyard and he had tried to cycle using the lines for orientation. He also thought that he had been able to recognize white lines/belts painted around square pillars in a shed of the schoolyard (painted on the advice of a low-vision teacher). His mother also told that perhaps he had seen some lines she once had drawn for him in the condensation on a bus window. The other subject maintained that sometimes he could see the white lines of the pedestrian crossings in the street and also contours/silhouettes of cars in contrast to darker/lighter background. Of course, it is possible that the other subjects have also seen something without retaining any memory of it. On the other hand, the visual impressions in these two seeing subjects could have been a case of mistaken identities from touch or hearing sense. In the experiment the subject who thought that he could see cars in certain light conditions was control4ested in varied conditions. Sometimes he could point out cars at a distance of 7-8 metres. Howevei; it could equally have been the sound shadow he recognized. When he was tested with snow in the streets he could not recognize a single car. In mobility education it is not unusual that blindfolded seeing persons are able to recognize cars as echoes from their own footsteps. In this connection a car seems to give especially good sound shadow. In the opposite case, white lines on asphalt and pillars seem to be evident visual impressions. Such lines also correspond very well to the optimum conditions on CCTV for among other things linear magnification and contrast. In her autobiography 'Emma and I' of Sheila Hocken, the authoress tells that at the age of seven she could read letters on the blackboard at close range. Gradually her visual acuity decreased until the age of nineteen, by which time she became totally blind. In the book she tells (when 30 years of age) that she no longer has visual memories from her childhood:

> As a child, I could see a little, but not enough to recognize people or things as more than vague images coming and going in a mist of colors that were blurred and dull **...** My mother and father were comfortable, warm shapes that I loved, but I had no picture of what their faces were really like. My consciousness of home centered on things like the smell of pies baking and the crackling sound and warmth of the fire, rather than its glow. But nothing else. (Hocken 1979, p.2-3).

This account from a person being visually impaired 'only', should further indicate that the practically blind subjects in the experiment must have attained much more restricted visual stimulation and information. In general, the conclusion may be that the subjects have seen something, but most of them no longer have memory of previous vision. At least, possible visual impressions were of such small degree of significance that they did not give lasting learning effects. Also, the visual impressions those two subjects reported were so indistinct, sporadic and unsure concerning case of mistaken identities from other senses, that they did not convey systematic learning, e.g. form perception. Probably, none of the subjects have received interpretable and/or generalizable sight impressions.

The next question is whether such persons could achieve higher reading speeds through training. The subjects' eye/hand coordination was poorly developed. Normally this coordination is developed over *5-6* years from birth until the child can, for example, dot the 'i' precisely. The subjects could not spontaneously and correctly point to the whole of the braille cell, in spite of the fact that it was 40>(linearly magnified. After less than 2 hours training, though, all the subjects could precisely point out not only the braille cell but also the individual points of the cell. Such rapid learning of a complex interaction between perceptual and motor functions indicates that the subjects must have developed a general predisposition through the use of pointing coordinated with other senses, e.g. pointing out where sound or smell comes from. The finding indicates two important aspects of perception and learning: The subjects could not previously have used their sight sense for practical purposes to a degree sufficient for the eye/hand coordination to become developed. Diagnostically this may be one of the criteria for the lack of vision being from birth and that their vision had not previously functioned better during the ontogenesis. Although the subjects managed to accomplish the pointing function quickly, the movement and localization had to be learned over a period of time. Could it be that, analogously with the pointing function, eye movements and eye fixation must be learned over a period of time in order to achieve, for example, precise and rapid reading? The capacity for learning, in intensity and time, would thus conceivably depend on individual predispositions in the subjects' general development. The results of the post4ests for visual braille, continuous text, seems to confirm such a hypothesis. The range of increased reading speed showed clear individual differences, and the increase in itself showed slow progression even in relation to the short period of training.

The data from the control groups have been compressed here, but all the same should be the subject of reflection, analysis, and discussion. Here, one may only state provisionally that control group I does not provide data for supporting the view that congenitally blind with light projection can achieve higher reading speed on CCTV than the subjects of the experimental group achieved. The number of subjects of control group 1 is so small, however; and the aetiological variations are so many in thispart of the blind population, that on no account may this be considered to be a final conclusion. Control group 2 provides strong indications that many persons with countsfingers from ad oculum to < 1 metre (practically blind) may derive great benefit from residual sight for reading purposes by the aid of CCTV. The same reservations as were appropriate for group 1 must be made However, as far as one knows, such data have not been published previously in the research literature.

The light sense of the subjects of the experimental group was present at birth and had been intact during their whole development. A number of deprivation experiments on animals (Hubel & Wiesel 1963, Blakemore & Cooper 1970; Hirsch & Spinelli 1970; Hohmann & Creutzfeldt 1975) have shown that if the sight sense is not stimulated in so-called critical periods or optimal learning phases it will not be possible later to rehabilitate it. The explanation of the phenomenon has been that the cells of the sense organ, neural pathways and the visual cortex permanently lose their ability to function as a result of lack of stimulation - the sense becomes deprivated. In humans too neuro-physiological deprivation has been shown, clinically with congenital astigmatism (Freemann, Mitchell & Millodot 1972) and experimentally with, inter alia, use of the so-called 'tilt after-effect' for the measurement of 'interocular transfer' (Hohmann & Creutzfeldt 1975).However, in experiments using translucent occlusion in newborn kittens, Hubel &Wiesel (1963) showed that the connection between the cells of the cortex striata develop with light perception only. This recognition may conceivably help towards explaining why the processing, neurophysiological function in the subjects of the experimental group could be rehabilitated when visual object stimulation was optimised by the use of electron-optical devices. Restricted use of light sense (without electron-optical magnification) can be defined as unstructured visual stimulation in that persons with that kind of sight handicap only perceive light and in the least case the number of fight sources and their respective positions. But the objects' details and general character, e.g. shape, size and surface texture, cannot be perceived with light projection only. The subjects' visual spontaneous recognition in the pre-tests of object characteristics, previously learned through touch, shows that through the visual stimulation which light projection had given, they must have retained a certain potential or inborn predisposition for visual perception of object. But does reading of visual braille presuppose the perception of form? Is not this kind of reading only a registration of a given number of points? The first question must be answered with a 'yes; the other with a 'perhaps not; based on the following reasons. The strictly theoretical foundation for the determination of vision is the eyes' ability to see light sources. 'It is

thanks to our sharpness of vision that it is possible to observe contours, forms and things' (Karpe 1975, p.35). In the terminology of optical instrumentation the equivalent function is called the power of image resolution, e.g. of a microscope or a TV screen. Normal sharpness of vision for letters is defined as the line which has a breadth equivalent to one minute of angle. This is called the least angular sharpness of vision. Thus, during vision testing, the eye's ability to distinguish between different sharpnesses is investigated, or in a more extended sense a measurement of form perception is carried out. On this theory the conventional methods of visual acuity testing are founded. In a more penetrating application, experimental research methods differ between threshold and supra-threshold levels using both single-spot stimuli and gratings, e.g. 'With single targets two threshold criteria have been used: detection where the observer reports the mere presence of the stimulus, and resolution or identification where the observer is requested to report upon some specified stimulus characteristics such as its form' (Lie 1980, p.967). In visual and tactile braille the points are separate circular forms. Readers of tactile bralile often assert that they 'think in' imaginary lines between the points. Applied to visual braille this would correspond to the lines of ordinary written letters. The subjects least angular sharpness of vision (retina's
resulution power) was, however, drastically reduced as a result of their eye disease.The total number of receptors in a normal reading finger is much lower than the corresponding number of rods and cones in a normal retina. All the same, the finger as an organ for reading has a resolution power good enough for high input of information (cf. Control Test with Tactile Braille, continuous text). Moreover, there is a wide-ranging research literature on tactile (skin) discrimination ability, showing that tactile resolution power in man is dependent both on number of skin-receptive cells and the stimulation intensity and frequency (BachY-Rita 1972; Nolan & Kedris 1969; Fjellsenden 1978). It would not be unreasonable, therefore, to infer that also a retina with a drastically reduced number of receptors will nevertheless possess a resolution power sufficient to allow the perception of form under optimal conditions. In the present experiment the cause of the subjects' perception of both visual braille (and ordinary letters) thus may be explained by the fact that the print image on the CCTV monitor corresponded with the retina's requirements for, among other parameters, linear magnification.
Both the hypothesis concerning the sight-functional potential in relation to electron optics, the research strategy (using visual braille) and the finding itself seems to be new in the research literature of the field. As far as it has been possible to confirm, nothing has been published on sight functioning with such a low criterion for 'vision,.

Cross-Modal Transfer of Learning
To understand cross-modal transfer is not easy. It is difficult enough to show that the process occurs at all, when it may begin and be present and under which external condition it develops and functions. It becomes considerably more difficult to explain how and why sensory and cognitive processes become established, develop and function as neurophysiological and pedagogical phenomena. Neither this study nor any other investigation known to the author adequately explain the mechanism behind the process. Nevertheless, any research finding which shows or clarifies some aspect of functional cross-modality, or lack of it, will be another step towards a better understanding. With this kind of general yet restricted aim as a background, some of the results of this experiment will be discussed in relation to other research findings in the literature.

In other experiments on cross-modal integration or cross-modal transfer, different kinds of cross-modality have been measured by different methods and on subjects having different preconditions. In addition, the communication of the results has been 'bedevilled by confusion' (O'Connor & Hermelin 1971). Investigations of cross-modality thus have not always been commensurable. O'Connor & Hermelin (1971) pointed out that in regard to cross-modal transfer one must, at the very least, distinguish between three kinds/methods: 1) Cross-modal matching; 2) Cross-modal discrimination; 3) Cross-modal transfer of principles. In the Bergen experiment all three methods were used. Matching, in that the graphical symbol in braille was visualized on the CCTV monitor; discrimination, in that letter and word images of visualized braille were presented in random order; and transfer of principles, in that reading of words and sentences in visualized braille presupposed that the dimension(s) syntactic/semantic function had been learned through touch.

The interpretations of the results are, however, dependent not on the choice of method alone, but also on the personal, and perhaps very different, capacities of the individual for sensory and cognitive function. In their multifactor theory, Kearsley & Royce (1977) assert that adequate understanding of individuality may be gained only by a theoret4cal integration of both multivariate and experimental research.

The theory distinguishes at the outset, and in agreement with Gibson's (1966) distinction, between sensing and perception which are defined respectively as energy processing and information processing. A hierarchy of sensory dimensions which include specific modality factors of a higher order; are then derived. The theory may be used in the interpretation of experimental investigations on sensory prerequirements and cross-modality.

Even though the sample in the Bergen experiment is small, it was shown that the subjects saw, recognized, identified and read visual braille on CCTV with full comprehension of content and without previous visual training. Persons with normal vision were able to read braille visuaily, but not before the signs and their syntactic/semantic function had been learned and established. The only way the subjects could have learned braille was through the modality of touch. The spontaneous and significant result of the visual pre-test for braille letters gives empirical support for cross-modal transfer of learning from touch to sight. The fact that the subjects also spontaneously identified the graphical punctuation marks on the first occasion of seeing them in continuous text lends further support to the thesis of cross-modal transfer in the experiment.

According to Gibson's (1969) classification of intermodal relations, syntax and semantics may be defined as amodal function. Applied to the Bergen experiment these amodal functions must exist as predispositions (cf. modal properties) among the subjects, thereby providing a crucial precondition for reading whole words and continuous text in relatively good reading performance in tactile braille.

But cross-modal transfer seems to demand additional predispositions which include specific modality factors of lower order and independent modality factors of higher order (Kearsley & Royce 1977; Walk & Pick 1981). If sensing is classified, according to Gibson's (1966) distinction, as a specific modality factor, the subjects' light projection must be classified as energy processing and thus must be counted as a predisposition of lower order. The light projection as a sensory function and predisposition was thus a precondition for the possibility that the subjects could ever manage spatial and form perception (information processing) in the matching and discrimination of the letters of visual braille. As an existential phenomenon, braille cells are synonymous with all other objects which can be visually perceived. It was thus not to be taken for granted that the subjects' visual identification of braille letters would enable them to read whole words and continuous text in visual braille. That they in fact did manage to do this even in the pre4ests is a significant result, which also may offer support for cross-modal transfer of previously learned syntactic/semantic functions in the tactile reading process to a simultaneous syntactic/semantic function in visual reading. Gibson (1969, p.230) says in her conclusion that if cross-modal transfer turns out to be dependent on invariant amodal information, then the term 'transfer' becomes inappropriate. The hypothesis need not be true. At issue might be the question of the possibility of direct cross-modal transfer of learning between variables of lower order at one level, and/or indirect cross-modal transfer of learning via variables of higher order at another level. Geschwind (1965) suggests that the parietal lobe is the anatomical basis for integration of information from all modalities and functions as an intermodal field of association. Whatever the localization, Geschwind argues against the view that speech, for example, is a precondition for cross-modal integration. It is more reasonable, he says, that the development of speech is dependent on a genuine human capacity for integrating visual, auditory, and motoric stimuli. Cross-modal effects from tactile to visual modality among apes (Rothblat & Wilson 1968) seem to confirm the independence of language, even though a type of language function among apes may not be excluded.

All the subjects of the Bergen experiment had a well-developed speech. It is possible that in the case of an experimental group containing members undei; for instance, 9 years (cf. Kiapper & Birch 1971) the subjects will recognize braille letters learned through touch when they are presented visually, but will not gain reading abilities of whole-words and continuous text in visual braille. The question must remain open, in that the Bergen experiment did not have control over the whole range of amodal function or independent modality factors of higher order such as age, intelligence levels, speech, already learned syntax/ semantics in reading, motoric performance levels and perhaps also differentiated preconditions for sequential/simultaneous perception. To the degree that general conclusions may be drawn from a small sample of subjects, the Bergen experiment showed that when amodal functions are established and internalized in individuals over 12 years of age, the specific modality variables of lower order (e.g. light projection and tactile sensivity) give cross-modal transfer from the tactile to the visual modality. It then becomes reasonable to draw the conclusion that sight function more than light projection, e.g., normal sight, receives transfer from e.g. the tactile modality. The demonstration that such a cross-modal processing takes place in human beings would have consequences for learning theories and for educational practice to a degree dependent on the extent of such transfer effect. It is, however, a problem for research to show that it occurs, in that simultaneous function of the visual and tactile modalities does not provide the opportunity for the proper testing of the transfer. This justifies, for instance, von Senden's (1960) postoperative method. The Bergen experiment has given empirical support for transfer effects from the tactile to the visual modality. The subjects were of normal development, having just one handicap - loss of sight. Within the frame of learning theories one may then state a more general hypothesis that what is learned through touch by so-called normally developed persons more than 12 years old is learned visually simultaneously. In this learning, both lower order and higher order modality variables enter. Perhaps it is a necessary precondition for the cross-modal transfer that *all* biological and cognitive functions are normally developed. Any retardation in one or more of the specific modality factors of lower order must thus be compensated for by reinforcement. The utilization of the electronoptical device of the Bergen experiment is, in that case, an example of such a compensating reinforcement at a level of energy processing which previously had seemed impossible to realize.

Concerning the significance of age for the achievement of crossmodal transfer (cf. Blank & Brigder 1964; Klapper et al. 1971), Piaget's (1926) thesis - that the ability for making abstraction is not developed before the age of eleven - might have renewed relevance. If the ability to make abstractions is defined as a collective production and a total integration of lower and higher order modality variables, one would not expect cross-modal transfer before a certain level of abstraction had been developed. On this question the Bergen experiment can say nothing, but the methods of the experiment have been designed to permit investigations also for subjects below 12 years of age.

It may be claimed that the interaction between the auditory modality and verbal activity must have had an influence as a reinforcement for the achieved results of the Bergen experiment, especially for reading of visualized braille in continuous text. But such reinforcement does not have to be a precondition for cross-modal transfei; at least not in relation to the auditory modality. That should be pointed out by the congenitally deaf-blind, who learn reading through the modality of touch, and only in interaction with hand-motoric function on special communication devices for the deaf-blind. But the effect of interaction cannot be dis-missed in general. Communication requires verification of cognitive functions, as a consequence of information input, through the releasing of motoric activity from one to another by the efferent neural pathways, in this case as a speech response. An investigation of cross-modal transfer of learning among the deaf-blind whose residual sight has been habilitated by means of an electron-optical device could offer additional information of fundamental interest for learning theory on the possible connection between speech and cross-modality.

In our previous investigation (Hunstad, Selnes & Krekling 1979; Hunstad & Selnes 1980) it was shown that no cross-modal transfer occurred, either from the tactile to the visual modality, or vice versa. Why was the result of the Bergen experiment different from this one?

Methodologically the investigations are comparable. But the earlier experiment biological and cognitive functions are normally developed. Any retardation in one or more of the specific modality factors of lower order must thus be compensated for by reinforcement. The utilization of the electronoptical device of the Bergen experiment is, in that case, an example of such a compensating reinforcement at a level of energy processing which previously had seemed impossible to realize.

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Methodologically the investigations are comparable. But the earlier experiment differs from the Bergen experiment in one important respect at least. In the 1979 experiment the subjects had measurable vision, differs from the Bergen experiment in one important respect at least. In the 1979 experiment the subjects had measurable vision, while the subjects in the Bergen experiment had only light projection. That no cross-modal transfer was obtained in 1979 may thus be due to visual object stimulation among the subjects in their development up to the time of the investigation. Even if their visual stimulation must have been weak and diffuse it might still have given enough learning effect for the comprehension of ordinary letters as objects, perhaps together with auditory, tactile, and verbal interaction. As an extreme example we may refer, in this connection, to the nativist objection (Hatwell 1978) to the results in the investigation of Gregory & Wallace (1963), who argued against the interpretation of associations from the patient's first 10 months of infancy, before he lost his sight and even if he could not have learned leners at that age. The visual stimulation of the subjects before the 1979 experiment must, in any case, have been stronger than for this patient. The increase of visual reading speed among the subjects in the 1979 experiment was unexpectedly great in relation to the short period of training they received. The result (1979), therefore, possibly explains more about the significance of these sight residues for learning than it explains cross-modality. This may be analysed and interpreted from another significant difference between the two investigations. In the Bergen experiment, visual braille was used as a medium for unveiling possible cross-modality. This medium (together with ordinary visual print and visual gemoetric figures) theoretically should offer a much more secure guarantee for transfer of established tactile reading ability/object perception (information processing) than the transfer value of *reading speed* from tactile braille to visual ordinary print and vice versa which the 1979 experiment measured. Speeds in general and reading speed as in this case, like e.g. jerky movements (Gibson 1969, p.219), must be defined as an amodal function in that speeds are common to several modes. As an amodal function, reading speeds offered no transfer in the 1979 experiment. But syntax/semantics in the reading process as amodal functions did show transfer in the Bergen experiment and probably in the 1979 experiment. An explanation for this may be that some amodal capacities of higher order (e.g. syntax/semantic functioning) convey cross-modal transfer to abilities of lower order (e.g. shape-, size- and location constancy of letters), whereas others do not. If the different pre- and post-tests used in those two experiments really measured the same and were equivalent, there is one thing more that the 1979- and the Bergen experiment have in common. The low identification and reading speeds (amodal capacities of higher order) which were measured in the Bergen experiment, even in the post4ests, suggest that reading speed did not show cross-modal transfer here either. On the contrary, the results of both investigations indicate that speed as a phenomenon is functionally specific for each modality. If reading speed is defined as a necessary criterion for effective reading, then it seems that each modality must receive initial training with its specific sense energy. No cross-modal transfer of e.g. reading speed may be anticipated. This is a real educational problem today in, for example, the choice of reading method (ordinary print and/or braille) for students with great visual handicap.

Finally, a word or two about one result of the Bergen experiment which might have some significance for subsequent research. Sight function achieved through the aid of electron-optics by the congenitally blind with light projection has shown that post-operative investigations are no longer the only possible method (Gregory & Wallace 1963; von Senden 1960; Umezu, Toni & Uemura *1975).* The utilization of electron-optics on human beings with congenital amaurosis/light projection gives at least equally favourable conditions for the measurement of cross-modality. This involves the possibility for using subjects (e.g. deafblind) and measurement of personality variables (e.g. language and abstraction abilities) in a more interdisciplinary and differentiated manner in the future.

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NOTE

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