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Does Daltonism influence young children's learning?

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Abstract

Anomalies in colour vision constitute a particular type of sensory deficiency whose influence in educational contexts has attracted surprisingly little research attention given its ubiquitous use in various learning activities as a code, an aid, or even as the focus of the activity itself, especially during early education. We here describe a three-part investigation of the incidence and influence of Daltonism in a sample of 1039 preschool children. In the first study, the incidence of Daltonism was found to be more than 5% of the boys and less than 0.5% of the girls. The second study looked at how well certain standard classroom tasks involving colour perception were performed, and confirmed the expected negative influence of Daltonism. In the third study, however, no significant differences were found between the two groups in their scores on standard preschool tests of acquired concepts and skills, whereas their teachers, who still did not know which of their pupils had colour vision problems, in responding to a curricular competence questionnaire assessed the Daltonic pupils as somewhat poorer achievers than the non-Daltonic group. The present results should help parents and teachers improve their awareness of this deficiency and of the limitations that it imposes on the early stages of learning.

Keywords: Individual differences in colour vision; Colour vision deficiency; Special educational needs; Early childhood; Early education

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1. Introduction

Many of the problems of learning that appear at the earliest ages are directly linked to easily detectable visual problems (Keymer, 1999). It has been demonstrated, for instance, that the visual skills of binocular fusion and accommodation are closely related to resistance to fatigue and to the successful performance of school tasks such as reading that require processing of visual stimuli (Hennessey, Losue, & Rouse, 1984; Scheiman & Wick, 1994). The growing awareness of these issues by physicians, vision specialists, and educators has led many countries to institute ophthalmologic testing in schools, especially for the first years of education. There remain, nevertheless, some visual parameters that seem to have attracted hardly any attention. One is the capacity for colour vision. What is usually known as Daltonism is a specific type of visual deficiency that is usually detected very late in development, even though it can play an important part in affecting early learning.

A person is considered to have standard colour vision when he or she is able to match any given colour to a mixture of three primary colours in the appropriate proportions (within a small margin of error). The most frequent anomalies are manifest in confusion of red and green hues (or colours that contain one or the other in their mixture), although there also exists a blue–yellow anomaly. The severest and rarest deficiency is achromatopsy, when the affected individual has hardly any colour discrimination and sees the world as if in black and white. These pathologies may have a genetic or an acquired origin. Classic genetic studies of the red–green anomalies showed them to be linked to the X chromosome, reflected in a much higher incidence in men.

There is some quite reasonable doubt about whether Daltonism really affects school performance at the earliest ages. The hypothesis that it does have an influence is based on two educational assumptions that almost all pre-primary teachers would support. One is that much of children's visual experiences from 3 to 6 years old is based on the use of colour as an attribute of objects, and in the first years of their schooling colour is routinely used to motivate and facilitate the assimilation of new concepts. The other is that colour perception is essential in a multitude of tasks in which the child's prior knowledge of the distinction of primary colours is taken for granted.

The importance of these considerations is particularly manifested in the learning processes of the area of "Communication and Representation", where colour is both an educational resource of normal use in various activities and a part of the learning content itself. The following are some applications of colour to just the basic concepts as examples:

- In many textbooks and in activities that teachers use spontaneously, colour is often used as a visual support for everyday concepts, objects, drawings, or vocabulary that still does not form a solid part of the pupil's linguistic repertoire (Gil, 1999).
- Concepts related to numbers and quantification procedures are usually worked on with abacus analogues and coloured objects.
- Spatial representation is frequently linked to the teaching of such concepts as geometrical bodies, flat shapes, and their relationships in space. Much of the curricular material that we have reviewed uses colour to aid in differentiating the said geometrical figures. In working on spatial orientation, teachers also often have recourse to colour in order to identify the objects in an illustration when they are presenting the relationships "up–down", "on–off", "inside–outside", etc.

Likewise, many teachers use colours as codes in activities designed to reinforce the concept of contiguity or orientation in the classroom's immediate environment (e.g., identifying desks by colour).

- With respect to temporal orientation, from a conceptual, procedural, and attitudinal standpoint, it is very positive for the pupils to identify and arrange their tasks in pre-set time periods. In the weekly schedule posted on a board for the pupils to interpret before beginning a task, it is usual to arrange the segments by colour, just as is usually the case with the days and months of scheduling calendars.
- In pre-reading activities, colour-coding is often used in linguistic segmentation tasks, and to facilitate the identification of the different forms of each letter in illustrations where colour is used to make a given letter stand out from other similar letters.
- It is therefore natural to expect that a defect in colour vision would interfere with the teaching–learning process in two ways. On the one hand, it would be an obstacle against successfully performing the learning activities of the area of "Communication and Representation". And on the other, it would bias the teacher's evaluation of the pupil's other skills that are involved in the execution of those activities.

The present empirical study therefore had a two-fold design—descriptive and experimental—with the following objectives. Descriptively, the aim was to determine the incidence of colour vision anomalies in a broad population of children of 4 to 6 years old. We shall call this Study I. Then in the experimental part, what we shall call Study II was aimed at evaluating the influence of these anomalies on learning in the area of "Communication and Representation", and Study III at determining the teachers' perception of the performance in class of pupils with colour deficiencies. There were three specific objectives that overlapped in Studies II and III: (i) to determine to what degree Daltonism affects the execution of educational tasks in which colours are used; (ii) to determine whether Daltonic children's results are significantly worse than those of their classmates with respect to the development of their visual perception skills and their acquisition of basic concepts; and (iii) to determine whether the teachers show evidence of a different perception of the learning skills of Daltonic pupils.

2. Study I: Incidence of Daltonism in the pre-primary population

This study was begun during the 1999–2000 school year, when the population of pre-primary school children (4 to 6 years old) in the Autonomous Community of Extremadura (Spain) was 14 000. As indicated above, the objective of this first descriptive survey was to determine as precisely as possible the incidence of colour vision anomalies in the school children of the last 2 years of this educational stage.

2.1. Method

2.1.1. Participants

The sample consisted of 1039 pupils (230 girls and 261 boys of 4 years old, and 258 girls and 290 boys of 5 years old), from 13 pre-primary schools in the Region, selected at random.

2.1.2. Materials

Visual deficiencies were evaluated using a mix of materials elaborated on the basis of three pseudo-isochromatic tests employed in colour vision anomaly detection. Isochromatic tests consist of plates with a coloured background and coloured foreground zones forming a figure designed to be imperceptible to observers with a deficiency in a particular chromatic channel. The method of preparing a plate is to design a background of dots of different sizes and grey-scale levels, distributed at random, and then add sets of dots with variations in blue–yellow and red–green hues (and random intensities) to form the different figures (Irtel, 1999). The present test was elaborated starting from two commercially available tests: the Ishihara Test (1996) and the Color Vision Testing Made Easy (CVTME) material (Waggoner, 1994). A third set of plates of our own design were prepared in order to incorporate material that would be reliable in application to children less than 6 years old (see Pardo, Pérez, & Suero, 2000). The complete test consisted of 15 plates—8 belonging to the Ishihara test, 3 to CVTME, and 4 of our own design. The configuration of the colours on each plate permitted a certain feature to be distinguished unless the observer had a deficiency in the perception of those colours.

Of the 15 plates, 13 detected possible colour vision anomalies, 1 classified anomalous subjects according to their type of anomaly, and 1 helped to confirm that the children understood the test they were to carry out. A child was classified directly as Daltonic if he or she was scored as anomalous by both the commercial tests. In the cases when the results of these two tests did not coincide, a third test (the D-15 panel test) was given, and in some cases an anomaloscope-type test.

2.1.3. Procedure

With respect to the *evaluation procedure*, we initially tried two alternatives. One was to present the plates individually using colour cards. The other was a collective presentation, projecting slides using a computer-controlled video projector. The preliminary trials showed that, despite the considerable cost in time, the first procedure was less risky both in the quality of the colours and in its greater technical and organizational simplicity.

The test was applied in a room with diffuse natural lighting (direct sunlight or artificial lighting may yield misleading results due to the design of the tests). The plates were presented individually at an approximate distance of 75 cm and allowing intervals of some 4 s for the subject to view and identify the figure. An identification template was provided for the pupil to indicate the figure that appeared on the coloured plate.

2.2. Results

Of the 1039 pupils evaluated, we detected 37 boys and 2 girls with evident signs of colour vision deficiency. This represents 6.71% of the masculine population and 0.41% of the feminine population, percentages similar to those obtained with adults (Wyszecki & Stiles, 1982). The mean of correct responses in the colour vision test was 11.78 out of 13 plates.

3. Study II: Performance of the Daltonic pupils in educational tasks that employ colours

Having quantified the incidence of Daltonism in the local pre-primary population, we wanted to analyze its influence in the classroom by comparing the behaviour of Daltonic and non-Daltonic

children. The following study was thus centred on exploring the two groups performance with respect to specific learning tasks that involve, together with other skills, colour discrimination.

3.1. Method

3.1.1. Participants

The sample consisted of all the pupils in whom some colour vision deficiency had been clearly detected, each matched with a randomly selected non-Daltonic classmate of the same age and gender. Hence, the total sample of Study II consisted of 78 pupils—74 boys and 4 girls—half of them Daltonic. The selection procedure of pairs from the same class naturally avoided any possible effect of the teachers' different educational styles, and we confirmed that there were no major differences between the groups in the external variables sociocultural level, use of eyeglasses, or auditive memory. The mean of correctly recognized plates out of the 13 possible was 2.13 in the Daltonic group, and 12.33 in the non-Daltonic group.

3.1.2. Materials

The two groups were given a performance test based on relatively simple tasks taken from a variety of school materials in the area of "Communication and Representation". Besides involving colour discrimination, these tasks were also directly aimed at working on visual-motor coordination and certain basic concepts related to numbers and to identifying and sorting geometrical figures (Table 1).

3.1.3. Procedure

The activities were presented individually to each pupil for about 50 min. Before the child carried out the activity, the teacher ensured that he or she had understood the corresponding instructions. The first 5 min were devoted to a simple test of auditive memory: the teacher named seven familiar objects at 2-s intervals, and then the child immediately marked with a cross the corresponding black-and-white

Table 1
Educational tasks used as evaluation material in Study II

Task no.	Objective	Description
1	Visual-motor coordination	Colour the fringes of the drawing of a scarf, following model
2	Numbering	Count the score on a target according to a code that associates numbers with colours
3	Combination	Mixing primary colours according to a model
4	Numbering	In a coloured drawing of a fruit-shop, identify the price of different fruit
5	Numbering	Count the beads of an abacus with the aid of their different colours
6	Numbering	Count coloured balls in a basket
7	Geometrical figures	Identify, and reproduce separately, geometrical figures marked with different colours in a composite picture
8	Geometrical figures	Reproduce the order of the pieces of a pyramid following size and colour criteria

Table 2
Percentages of pupils who successfully carried out school-level tasks that required correct colour discrimination in Study II

Group	Learning tasks							
	T1 (%)	T2 (%)	T3 (%)	T4 (%)	T5 (%)	T6 (%)	T7 (%)	T8 (%)
Non-Daltonic	100	100	97	100	100	100	100	100
Daltonic	87.5	34.4	6.2	15.6	12.5	84.4	75	25

drawings on an answer sheet. The child then carried out eight tasks involving colours in the order given in Table 1 (the order was not balanced across participants). The respective teacher, who did not know whether or not the pupil was Daltonic, evaluated the performance of the tasks, taking as the criterion of success that the subject made no mistakes.

3.2. Results

There were no significant differences between the groups in the memory tasks (no colour involvement). In the educational tasks (involving colour), however, the non-Daltonic pupils were judged as performing better. Table 2 gives the percentages of success for the two groups. One observes that practically all of the non-Daltonic pupils responded appropriately to the tasks, according to their teachers' judgement. Most of the Daltonic pupils, however, made constant errors of execution, especially in the tasks relating to counting and the identification of numbers. Their performance was evaluated as poorer than the non-Daltonic group in all of the exercises.

4. Study III: Influence of a colour vision anomaly on preschool-level learning in the area of "Communication and Representation"

The previous results immediately suggested two hypotheses:

(i) The first hypothesis was that difficulties of colour perception in educational tasks at the pre-primary level cause Daltonic children to have a significantly poorer school performance than their classmates, particularly in regard to the acquisition of the basic concepts of the area of "Communication and Representation". This hypothesis could not be tested using such specific tasks as in Study II. It required a more general evaluation of the learning of verbal, quantitative, and spatial and temporal concepts (as well as other visual perception skills in which there is no demand for colour discrimination).

(ii) Does a teacher who explains to a Daltonic child that the red figure is a circle misinterpret the child's subsequent difficulties as a failure to grasp the geometrical concept when the problem really lies in the perception of the colour? The second hypothesis was, therefore, that colour vision anomalies do not so much directly affect learning as indirectly, leading the teacher to have a biased perception of the pupil's other skills (such as those in the second column of Table 1). This hypothesis would be confirmed if there were a discrepancy between the results of the evaluation referred to for the first hypothesis and the teacher's evaluation of the pupil's learning skills.

4.1. Method

4.1.1. Participants

The participants were the same 78 subjects, 39 Daltonic children and their corresponding randomly selected non-Daltonic pairs as in Study II.

4.1.2. Materials

The aim was to determine whether the differences observed in Study II between the two groups in their performance of specific educational tasks significantly affected other skills of "Communication and Representation" at the pre-primary level. In particular, the objectives were to analyze: (a) visual-motor and visual-perceptive skills; (b) the level of acquisition of basic concepts; and (c) the teachers' perception of the curricular competence of each child in the area of "Communication and Representation". Three types of evaluation material were used.

(a) To evaluate visual-motor and visual-perceptive skills, we applied the instruments of perceptive aptitude and visual-motor coordination of the Preschool Diagnosis Test (T.E.A., 1991). In the perceptive aptitude instrument, the child had to match objects that had the same shape or spatial position as a model ("constancy of form" and "spatial position"), and to locate an the outline of an object within a tangle of straight lines and curves ("figure-background discrimination"). In the visual-motor coordination instrument, the child had to trace a continuous line without lifting the pencil from the paper and without leaving a set path.

(b) The level of acquisition of basic concepts was evaluated directly by individual application of the Bohem Test (1979) of spatial, quantitative, and temporal concepts, and the instruments of verbal and quantitative concepts from the aforementioned Preschool Diagnosis Test. In both tests, the child had to choose from various alternatives the drawing that matched a spoken phrase which included a key concept.

(c) The teachers' perception of their pupils' learning problems was determined using a 15-item questionnaire to evaluate curricular competence in the area of "Communication and Representation" at the level of the last 2 years of pre-primary education. The teachers assessed their pupil's acquisition of each skill on a 4-level Likert scale ("Not reached", "In progress", "Reached", "Outstanding"). The following are typical examples of the items: [Does the child. . .]. . .understand the instructions given for carrying out classroom tasks?
. . .interpret the illustrations to written text by relating the two?. . .classify and sort drawings and figures following a pre-set criterion or sequence?. . .use basic spatial notions to place or move objects?. . .solve problems that require the application of simple operations (remove, add)?

4.1.3. Procedure

The children's tests were applied individually by one of the researchers in two consecutive sessions. In the first, of about 40 min, the children did the tasks of the Preschool Diagnosis Test in the following order: verbal concepts, quantitative concepts, perceptive aptitude, and visual-motor coordination. This was followed by a 30-min break. Then, in the second session of about 20 min, they responded to the items of the Bohem basic concept test. Finally, each teacher completed the curricular competence questionnaire for each of their participating pupils without knowing the respective colour vision impairment diagnosis.

Table 3
Means and standard deviations of the visual-motor coordination and perceptive aptitude scores (Preschool Diagnosis Test) for non-Daltonic and Daltonic groups in Study III

Group	Visual-motor coordination		Perceptive aptitude	
	M	S.D.	M	S.D.
Non-Daltonic	7.56	2.40	27.87	10.24
Daltonic	7.05	2.84	24.23	10.24

4.2. Results

One observes in Table 3 that the non-Daltonic pupils scored slightly higher on the visual-motor and visual-perceptive instruments of the Preschool Diagnosis Test, although none of the differences were significant in a Mann–Whitney *U*-test.

This result was not in accord with hypothesis (i) above, and indicated that, unlike most vision problems that have been investigated, the specific character of colour vision anomalies means that they do not necessarily affect general visual perception skills (visual-motor coordination, visual discrimination, constancy of form, spatial position, spatio-visual orientation, and figure-background discrimination), at least in tasks not involving certain colours. Furthermore, the failure to find significant differences in the performance of black-and-white perception tasks, such as background-figure discrimination, lends support to the validity of the isochromatic tests (in which the Daltonic pupils had far greater difficulty in distinguishing figures formed by certain colours).

Neither did the acquisition of basic concepts results (Table 4) support hypothesis (i). One observes that the mean scores of the two groups were also very close, with no statistically significant differences.

The overall results of the two tests were significantly correlated (r=0.69, p<0.01). There was also a high level of correlation (up to 0.66) between these results and the scores on the perceptive aptitude tasks. In contrast, there was hardly any correlation between the scores on the Bohem test and the colour vision test (r=0.07; p<0.01).

Hypothesis (ii), however, that colour vision anomalies bias the teacher's perception of the pupil's other skills, was supported by the differences between the groups found in the teachers' evaluation of their pupils' curricular competence (Table 5). In particular, the teachers' assessment was that the Daltonic pupils had not sufficiently developed an average 6.3 of the 15 skills of the questionnaire (i.e., 42.4% of the items were scored as "Not reached" or "In progress"), whereas this proportion was 4 out of 15 (27.2%) for the non-Daltonic pupils. (Recall that the teachers were still unaware of which pupils had been diagnosed as Daltonic.)

Table 4
Means and standard deviations of the test scores of the acquisition of verbal, quantitative, spatial, and temporal concepts for the non-Daltonic and Daltonic groups in Study III

Basic concepts	Preschool diagnosis test						Bohem test			
Groups	Verbal		Quantitative		Spatial		Quantitative		Temporal	
	M	S.D.	M	S.D.	M	S.D.	M	S.D.	M	S.D.
Non-Daltonic	11.69	1.61	10.18	1.70	18.72	2.24	11.97	1.90	2.77	0.96
Daltonic	11.54	1.55	9.97	2.18	18.31	2.97	10.82	3.66	2.92	2.00

Table 5
Results of the teachers' responses to the curricular competence questionnaire in Study III (means and standard deviations of the frequency of the 15 curricular skills "not reached", "in progress", "reached", and "outstanding" for the non-Daltonic and Daltonic groups)

Criteria	Not reached		In progress		Reached		Outstanding	
Groups	M	S.D.	M	S.D.	M	S.D.	M	S.D.
Non-Daltonic	0.49	1.52	3.59	2.96	9.72	3.79	1.18	2.92
Daltonic	0.67	1.58	5.69	3.58	7.79	4.38	0.61	2.51

The curricular competence evaluation was more closely correlated with the overall Bohem test scores (r=0.44, p<0.01) than with any other of the variables analyzed.

5. Conclusions

The incidence of colour vision anomalies in a broad sample of 4- to 6-year-olds (Study I) was found to be relatively high and similar to that reported in the literature for other age ranges.

Initially, difficulties in the discrimination of colour were found to influence negatively the performance of various standard learning tasks in the area of "Communication and Representation" taken from preschool-level textbooks (Study II). Given how young the subjects were, there was always the possibility that the fatigue of a 50-min session would affect the results. However, no clear differences were observed in the performance of the first four and the last four tasks.

This confirmation of consistent errors in common curricular activities involving colour vision naturally suggested the hypothesis that the learning processes of Daltonic pupils are under severe risk. This hypothesis, however, was not confirmed by the results of Study III (Table 3: visual-perceptive aptitude with black-and-white tasks; Table 4: the acquisition of basic concepts) which detected no significant differences in the school performance of Daltonic pupils relative to their non-Daltonic classmates. However, the teachers' perception was that the overall learning of the Daltonic pupils was somewhat poorer than that of their non-Daltonic classmates (Table 5).

There are several possible explanations for these results. There seems to be little doubt that the presence of colour vision anomalies is not as relevant to school performance as other visual, cognitive, or sociocultural factors. Additionally, school materials include many activities in which colour discrimination is not fundamental. At any event, the most likely situation is that teachers implicitly provide other types of aid, especially verbal, when a Daltonic pupil has some initial difficulty with a task involving colours. There is also the possibility that some Daltonic pupils develop strategies to counterbalance their innate disadvantage, as has been observed with other types of sensory deficiencies. In our own educational experience with Daltonic pupils, we have found that many of them learn to discriminate colours by memorizing tones of grey (to which they then assign colour names) or by associating the names with the objects and specific shapes in which those colours are usually presented. In addition, contrary to popular belief, Daltonic pupils do not usually "exchange" colours. Most commonly they perceive two of them, red and green, in very similar hues (which only under very specific circumstances could lead to confusion). An interesting goal for future work is to compare the behaviour of Daltonic pupils with learning problems and those without, in order to determine whether the latter have developed learning strategies in school to counterbalance their visual deficiencies.

It also seems that Daltonism, rather than directly affecting learning, may instead bias the teacher's evaluation. The mistakes that Daltonic children make in tasks involving colours may be misinterpreted by the teacher who is unaware of the disability as learning difficulties of a non-visual nature.

In sum, there is a clear need for advances not only in the treatment of vision problems, but also on three fronts in the development of preventive educational measures aimed directly at school-level learning: early diagnosis and evaluation, specific vision training and teacher education. It seems clear that, the younger the subject, the more effective will vision evaluation and rehabilitation be, due to the greater plasticity of the visual-cortex system (Scheiman & Gallaway, 1996). Additionally, the secondary effects of Daltonism could be considerably reduced if the teachers had information about which of their pupils have colour vision anomalies and the type of that anomaly. It was particularly notable, in this sense, that in most cases the response of both parents and teachers to the diagnosis of a child's colour vision anomaly was one of surprise, even disbelief. Only a few of them had suspected that the child was Daltonic. The finding that more than 6% of the boys were already suffering colour vision related anomalies before beginning primary education is a worrying datum in view of the sparseness of knowledge concerning the problem. Hence, another important objective for future work with respect to this or other visual deficiencies must be to focus on initial and on-going teacher education with respect to vision in learning and teaching. It is our intention to study conjointly with in-service teachers paedagogical alternatives for these special educational needs, which have up to now received little attention.

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