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The development of separability in visual perception*

RÉGINE KOLINSKY
Université Libre de Bruxelles, Belgium

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Abstract

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Under conditions that do not allow focused attention, reports of illusory conjunctions (i.e. errors that wrongly recombine the features of different objects) constitute evidence of the separate registering of features at an early processing level. The occurrence of illusory conjunctions was used to determine whether there is preattentive analysis of component dimensions (colour and form) and of parts of shapes (triangles and arrows) in young children aged 5 to 8 years. Evidence of preattentive analysis was found, even for the youngest children, for colour and form but not for parts of shapes. Although developmental effects hardly reached significance, inspection of abilities assumed to affect the illusory conjunctions phenomenon suggests that at the preattentive stage children can integrate spatially separate segments but lack the capacity to fully analyse connected segments.

A central question in the study of perception is the nature of the units into which the sensory world is analysed. Given that in a hierarchy of processing operations different units may be extracted at different stages, the question of whether perception is analytic or integral must be asked separately for the

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Requests for reprints should be addressed to Régine Kolinsky, Laboratoire de Psychologie Expérimentale, Université Libre de Bruxelles, 117 Av. Adolphe Buyl, 1050 Bruxelles, Belgium.

different stages of processing. Holistic impressions are frequently the first introspectively accessed. However, earlier stages of processing could involve a system of analysers. Alternatively, human adults have certainly developed high-level capacities of *postperceptual* processing, which render them able to analyse at least some stimuli, even if these are perceived holistically under first impression. Treisman (1986a) proposes to distinguish between a structural, built-in analysis, assumed to be relatively independent of development, subsequent holistic impressions, and optional analytic strategies that would be set up through learning in particular contexts.

These distinctions are seldom discussed in theories of perceptual development. A classical view is that young children perceive multidimensional objects as unitary, undifferentiated wholes (Bruner, Olver, & Greenfield, 1966; Gibson, 1969; Werner, 1948, 1957). A recent related view adds the assumption that development proceeds from sensitivity to overall similarity relations between stimuli to sensitivity to dimensional identity. Several results have shown that young children mainly use overall similarity relations in the free classification of multidimensional stimuli, that is, in tasks where they may choose the basis of their sorts (e.g., Kemler, 1982a; Smith & Kemler, 1977). This view is known as the *integrality–separability hypothesis* (Shepp, 1978; Smith & Kemler, 1977) because it relies on the distinction made by Garner (1974) between separable and integral dimensions. In tasks of constrained speeded classification where categories are defined by the levels of one specified dimension, young children display integrality on pairs of dimensions that are separable for adults (Shepp, Barret, & Kolbet, 1987; Shepp & Swartz, 1976). That is, they display interference in a *filtering* condition (Posner, 1964) where selective attention to the target dimension is needed since the other varies orthogonally, and a redundancy gain when both dimensions vary in a correlated way, in comparison to a condition where only the specified dimension varies.

The integrality–separability hypothesis initially suggested that children and adults have qualitatively distinct modes of perceiving. However, this claim seems too strong (see discussion in Kemler, 1983; Smith, 1985). First, even young children can, under certain task procedures, compare and classify objects on the basis of dimensional identity (e.g., Kemler, 1982b; Kemler & Smith, 1979; Smith, 1979, 1984). Second, the integrality pattern displayed by children does not necessarily imply that dimensions are irrelevant. Young children, but not adults with most integral dimensions, behave differently when stimulus sets are organized around the axes that define the dimensions of the stimulus space rather than around arbitrary axes (Kemler, 1982a; Smith & Kemler, 1978). Furthermore, if young children respond only in terms of the overall similarity relationships of integral units, they should perform a classification task that requires *condensation* (Posner, 1964) more rapidly than one that requires filtering. Although condensation requires taking all dimensions of the stimuli into account, between-category dissimilarity is higher and within-category dissimilarity is lower in this task than in filtering. However, that prediction was not supported for young children (Kemler & Smith, 1978; Smith, 1980), whereas it was verified for both adults and older children with integral dimensions (Gottwald & Garner, 1975; Smith, 1980; Smith & Kilroy, 1979).

Some results obtained with babies using the habituation and generalization techniques are even more puzzling for the integrality–separability hypothesis. Cohen and Gelber (1975) found that 4-month-old infants detect a change in either of two dimensions, but not a change in the conjunction of values on the same dimensions: they display no recovery when tested with a green circle and a red triangle after habituation to red circles and green triangles. Therefore it seems they perceive the stimuli in terms of their old components rather than the new compounds. Fagan (1977) found that 5½-month-old infants respond to colour–form compounds as well as to components (see Cohen, 1979, for an overview on that topic).

The developmental picture appears confused unless one considers that the responses obtained in the different tasks may not reflect the same stage of processing. Indeed, in young children there could be an early analysis of component features or dimensions that would affect behaviour in recognition tasks but that would be unaccessible for some classification purposes. Moreover, classification studies with adults also show diverse results. For example, adults may use overall similarity relations with otherwise separable dimensions when performance in free classification tasks is constrained by time pressure, stimulus complexity, addition of a concurrent task, or instruction to respond under first impressions (Smith & Kemler-Nelson, 1984; Smith, 1981; Ward, 1983, Ward, Foley & Cole, 1986). Thus, depending on the task, adult subjects may respond on the basis of either holistic perceptual experience or componential analysis of the stimuli. Whether this componential analysis precedes the holistic percept or is accomplished subsequently is, of course, another question. In any case, it is unreasonable to make the general statement that adults and children differ in that adults process information in an analytic way, whereas children do not. A more acceptable hypothesis is that both adults and children may process analytically at a first stage of processing, but that children have limited access to either early analytic codes or postperceptual analysis.

One major difficulty in exploring processing codes, either in development or in the final state, lies in the possibility that some codes might never be directly accessed or experienced. They could be the processing consequences of *modules* (Fodor, 1983), that is, of highly specialized and autonomous systems, characterized among other properties by *limited central access*. This means that no intermediate stage of coding would be available for introspection, strategic modification or control behaviour. So, "indirect inferences may be better guides to the early perceptual codes than any attempt to tap them directly through introspection or instrumental responses" (Treisman & Paterson, 1984, p. 13).

One form of indirect evidence of early perceptual analysis has emerged from a recent proposal about the role of focused attention in object visual perception (Treisman, 1985, 1986b; Treisman & Gelade, 1980; Treisman & Souther, 1985). This proposal, the *feature-integration theory*, distinguishes between a preattentive stage at which the primitive attributes are extracted in parallel across the visual field, and a subsequent stage at which these attributes are recombined to form the complex objects we perceive. More precisely, the visual system first registers the primitive features of perception in separate sets of features maps, for example one for colour, one for orientation, and so forth. It follows from this account that "preattentive parsing cannot be available to consciousness" (Treisman, 1982, p. 212), since we do not experience shapeless colours or colourless shapes, but always some combination of the two. As Treisman (1982) herself notices, this account sharply differs from the classical view (see, for example, Neisser, 1967) that equates preattentive organization with phenomenological organization, that is, with the global, conscious, impression of regions outside the current focus of attention. According to Treisman, within each set of maps, the spatial relations of the visual world are preserved. When an object has a feature that is not shared by other objects in the visual field, it would be possible to detect directly the presence of activity in the map that corresponds to that feature. However, when two or more objects varying along the same attributes are simultaneously present in the visual field, the features must be localized to allow detection of the correct combinations of features. If one assumes that the different feature maps are totally unrelated, one must hypothesize a mechanism that allows correct alignment of one feature map with another. The model proposes focal attention to be the mechanism that matches locations across the different sets of feature maps. Focal attention would act via a master map of locations in which any discontinuity in intensity, colour, and so forth, is registered without specification of what the discontinuities are. Attention would conjoin, through the links between the master map and the sets of feature maps, all the features that are present in a selected location. This would be done serially for each selected location in turn, that is, for each object to identify.

Thus, according to Treisman, absolute location performs the special role of medium that carries information on other attributes, a suggestion made by Kubovy (1981). Focal attention, via the use of location, acts as a *glue* that holds the different features of an object together.[1] This model appears unparsimonious, since it assumes that three different mechanisms perform the apparently easy task of object identification: one to detect what the features are, another where they are, and a third that links the features according to their location. But various empirical findings, such as *pop-out* effect *versus* serial processing in search tasks, texture grouping and camouflaging, and the correct identification of feature targets without correct location, support the basic distinction between separate representation of primitive features and subsequent conjunction (see, for example, Treisman, 1982; Treisman & Gelade, 1980; Treisman, Sykes & Gelade, 1977).

Since object identification is supposed to require a stage of focused attention to each object in turn in order to ensure the correct allocation of attributes, a counterintuitive prediction is that when attention is diverted or overloaded attributes from different objects are free-floating and can sometimes be wrongly recombined to form *illusory conjunctions*. Illusory conjunctions are defined as new objects mentally constructed by the incorrect joining of attributes extracted from separate objects. They are evidence against holistic perception: if attributes can be wrongly recombined, they must have been separately registered as independent entities at some, presumably early, stage of processing.

As far as non-linguistic units are concerned, one may observe illusory conjunctions of colour and shape (Eglin, 1987; Prinzmetal, Presti, & Posner, 1986; Treisman & Schmidt, 1982), of colour, shape, size and "solidity" (outlined *versus* filled-in shapes) (Treisman & Schmidt, 1982), and of parts of shapes (Kleiss & Lane, 1986; Prinzmetal, 1981; Treisman & Paterson, 1984; Wolford & Shum, 1980). Illusory conjunctions have been observed in different tasks: verbal free recall (Eglin, 1987; Treisman & Schmidt, 1982; Wolford & Shum, 1980), verbal partial report (Treisman & Schmidt, 1982), successive matching (Treisman & Schmidt, 1982; Prinzmetal et al., 1986), simultaneous matching (Treisman & Schmidt, 1982) and detection (Kleiss & Lane, 1986; Prinzmetal, 1981; Treisman & Paterson, 1984). Most of these studies estimate illusory conjunctions by comparing the number of wrong combinations of attributes that were present in the display (*conjunction errors*) with the number of reports containing one or more attributes that were not present

[1]In this model, *focal attention* refers to the particular mechanism of feature integration. Even though this mechanism has limited capacity and allocates attention in a spatially constrained way, it is not necessarily the same mechanism which Posner (1980) assumes to deserve the enhancement of performance in a spatially restricted region. Some empirical data support the view that they are not the same (Briand & Klein, 1987).

in the display (*feature errors*), which reflect simple attribute misperception.

An alternative to Treisman's perceptual interpretation of illusory conjunctions is that connections between features tend to break down after identification of the stimulus while it is held in memory. However, the data only partially support the view that illusory conjunctions depend on memory delay. Treisman & Schmidt (1982) observed illusory conjunctions with coloured letters in both successive matching and free recall, even if they were less frequent in the former than in the latter task. Thus, memory failures in free recall can contribute to but are not crucial to the illusory conjunction phenomenon. Moreover, the large majority of conjunction errors observed in free recall were made on the first item reported. Memory interference from earlier reports of colours and shapes on the same trial is therefore unlikely to be a major factor in producing conjunction errors. Illusory conjunctions were also found to occur both with a simultaneous matching task, where the subjects had to detect the presence of at least one identical pair of stimuli in the display, that is, where there was no memory delay at all (Treisman & Schmidt, 1982), and in detection tasks where the target remained constant throughout the experiment, and exposure durations were very short (Kleiss & Lane, 1986; Prinzmetal, 1981; Treisman & Paterson, 1984).

The notion that illusory conjunctions give evidence of separability at an early stage of processing is supported by the fact that they do not occur when focusing of attention is allowed. In a task where subjects had to report what they saw in a cued location, Treisman and Schmidt (1982) found that, when no primary task prevented focal attention and when the relevant location was precued, subjects made as many feature errors as conjunction ones. Conversely, when focal attention was prevented by adding a primary task and postcuing the relevant location, conjunction errors dominated. The overall difficulty, that is, the total number of errors, was kept the same in both conditions by reducing exposure durations when attention could be focused on the relevant items. One problem is that the proportion of feature errors might be expected to be greater with shorter exposure durations, but it was avoided by Prinzmetal et al. (1986), who equated feature errors in the two cue conditions. The authors found under these conditions and in a situation where subjects made almost no feature errors that attentional factors affect feature integration (see also Eglin, 1987, and Kleiss & Lane, 1986, for other relevant data).

Other results seem to contradict the idea that illusory conjunctions reflect an early stage of processing. Virzi and Egeth (1984) suggested that illusory conjunctions may occur not only with perceptual features but also with high-level codes such as semantic representations. These authors observed what they called *propositional conjunctions*. For example, when the word "RED" was present in a display together with two other words, subjects tended to illusorily combine one of the words that was present in the display with red *ink*. Conversely, when there was red ink in the display, subjects sometimes reported the presence of the *word* "RED", illusorily combined with a colour ink that was present in the display. The so-called *perceptual conjunctions* observed by Virzi and Egeth (1984) are also puzzling: they arise between *whole words* and their colours (e.g., subjects report seeing "BIG" in black ink in the display "BIG" in red, "BLUE" in brown and "WIDE" in black), whereas Treisman and Schmidt (1982) and Prinzmetal et al. (1986) observed illusory conjunctions at the level of *letters* (i.e., between letter forms and letter colours). These two sets of results may suggest that reports from brief displays involve reconstructive processes that combine whatever information may be persisting from the display in an ad hoc fashion. However, the fact that one may observe propositional illusory conjunctions and whole-word perceptual conjunctions does not preclude the possibility that other illusory conjunctions reflect earlier codes. The task used by Virzi and Egeth (1984) was verbal free report, and thus implies a strong memory load. When this memory load is reduced by using a detection task with a constant target, neither propositional conjunctions nor whole-word illusory conjunctions are observed (Kolinsky, 1988). These errors are thus probably the consequence of memory confusions, arising after the stage at which features are conjoined by focal attention. This discussion shows that it is unwise to generalize from observations based only on a free report task. As suggested by Treisman and Schmidt (1982), it might be better to minimize the role of verbal coding and memory load by using a detection task.

The present study was aimed at determining whether or not preattentive analysis occurs in young children's perceptual processing. It used the illusory conjunctions technique. We did not ask children to analyse stimuli, but looked at errors that are indicative of analysis. In addition to adult controls, children aged 5, 6 and 8 years were studied, since it has been observed in classification tasks that 5-year-olds display integrality whereas older children begin to display separability (e.g., Shepp et al., 1987; Shepp & Swartz, 1976). Experiments I, III and IV were concerned with the development of part separability in perception. Materials and procedures were similar to those of Treisman and Paterson (1984, Experiment 4). These authors argued against the idea that a shape like a triangle is preattentively processed as a unitary gestalt. Testing adults on a detection task in which the target was a tilted dollar sign, they found that diagonal lines of right-angle triangles conjoin with tilted Ss to produce illusory dollar conjunctions as often as unattached, spatially separate, diagonal lines. This result supports the view that triangles are analysed perceptually into component parts that are not more "sticky" at the preattentive stage than unattached lines. Experiment II was concerned with the development of dimensional separability. The dimensions of colour and form were used. To avoid both alphanumeric knowledge and an important memory load, geometrical forms and a constant target were used as in the other experiments, rather than letters and a varying target as in the experiments of Treisman and Schmidt (1982). Since illusory conjunctions are supposed to reflect separability in early perceptual processes, and since these processes are supposed to appear very early in development, the prediction was that there would be no difference between adults and young children in the illusory conjunctions estimates for either parts or dimensions.

Experiment I: Illusory conjunctions of parts of shapes

Method

Stimuli and procedure

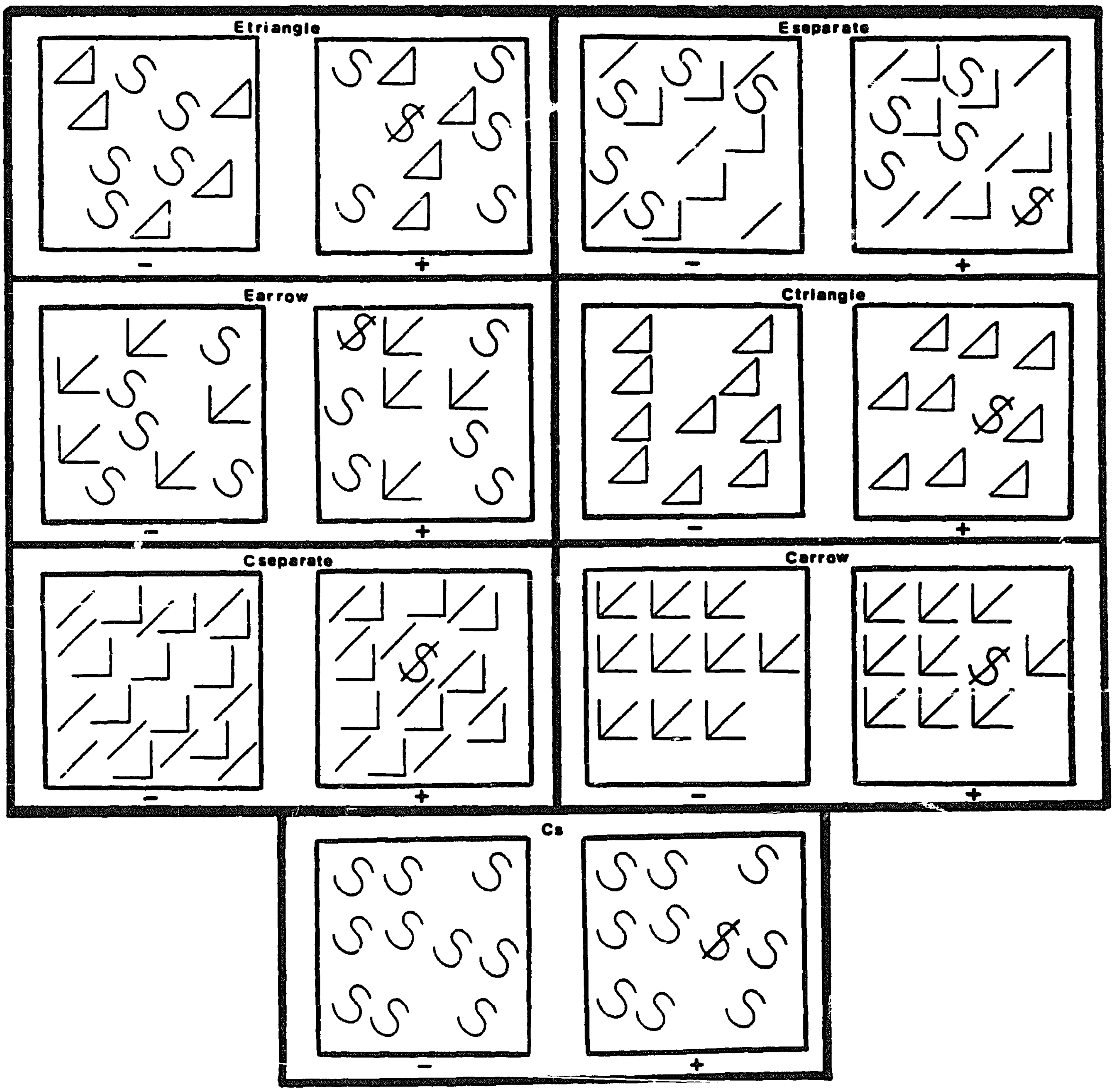
Examples of displays are presented in Figure 1. Each display contained 10 items. Target-absent experimental displays (*Etriangle*−) contained 5 right-angle triangles and 5 tilted Ss. Target-absent control displays contained either 10 tilted Ss (*Cs*−) or 10 triangles (*Ctriangle*−). The target was a tilted S with a diagonal line in the same orientation superimposed across the centre to make a tilted dollar sign. Diagonals and Ss were always tilted on the right. The target was present in 30 percent of the trials, replacing one of the items in the display; on target-present experimental displays (*Etriangle*+), it replaced a triangle half the time and an S the other half. Eighteen different arrangements were constructed for Etriangle− displays, 8 for Etriangle+, 9 for Cs− and Ctriangle− and 4 for Cs+ and Ctriangle+. In the target-present displays, the different arrangements were selected so that the target position varied between displays.

The 10 items were haphazardly scattered within an 8.3° × 8.3° area. Each individual item subtended 1.4°. The stimuli were drawn in black ink on white cards. Background luminance was 4.34 mL.

The experiment was run using an Electronic Developments three-field tachistoscope. The displays were preceded and followed by a random black-and-white noise mask exposed for 600 ms. The task was to decide, on each trial, whether or not the target was present. Between trials, an otherwise white field was occupied by a black central fixation dot.

The session took about 30 min for adults and 45 min for children. For all subjects, it included four blocks of 52 trials each, one for practice and three experimental. The different types of displays were mixed within blocks. Or-

Figure 1. *Example of each type of display used in Experiments I, III and IV. E = experimental displays; C = control displays; − = target-absent displays; + = target-present displays.*



der in each block was constrained to prevent the occurrence of more than three successive displays of the same type and of more than three successive displays containing the target. Subjects were first shown an example of a card with the target and one of each display type. For children, but not for adults, the same examples were then tachistoscopically presented, first at an exposure duration of 3 s, then 2 s, then 1 s, and finally 500 ms. Feedback was provided during this phase, but not later on. Throughout the session, the experimenter regularly showed the target in normal vision to the children. All the subjects were given one block of practice starting at 500 ms and gradually decreasing to the exposure duration used at the beginning of the first experimental block (60 ms for adults and 100 ms for children). Then, exposure durations were adjusted for each subject until the end of the session by a staircase procedure taking only control trials into account. After seven correct responses, the exposure duration was decreased by 10 ms; after an error, it was increased by 10 ms. A ceiling of 250 ms and a floor of 20 ms were imposed. Mean exposure durations during the experimental phase were 71 ms for adults (from 42 to 101, SD: 17), 105 ms for kindergarteners (from 79 to 170, SD: 25) and 124 ms for first-graders (from 88 to 173, SD: 31).

Subjects

The adult subjects were 12 undergraduate students, 6 women and 6 men, aged 19 to 28 yr, who were paid for their participation. The children were 10 kindergarteners, 5 girls and 5 boys, aged 5;5 to 6;3 yr (mean: 5;10 yr), and 12 first-graders, 3 girls and 9 boys, aged 6;3 to 7;2 yr (mean: 6;9 yr). All the children were tested in the second half of the school year. They were attending classes in a public school in Brussels, and came from families of middle to high socio-economic level. Six additional children were discarded: three kindergarteners because they refused to complete the session, one who was suspected of mental retardation, and one first-grader who never made false detections. Two adults were also discarded because their overall mean percentage of correct detection was very low.

Results and discussion

Table 1 presents the mean false detection (FD) and correct detection (CD) percentages for each type of display. As in Experiment 4 of Treisman and Paterson (1984), an estimate (called here ESTIMATE 1) of illusory conjunctions was calculated by subtracting from the total percentage of FDs made on experimental displays the sum of the percentages of FDs obtained on the two types of control displays (see Table 1). Since these displays contained only one of the two figures that appeared on experimental displays, FDs on

Table 1. *Experiment 1: Mean percentage of false detections (FD) and of correct target detections (CD), mean signal detection measures* (d' *and* Beta) *for each type of display, and mean estimates of illusory conjunctions in each group, taking as baseline control value either the sum (ESTIMATE 1) or the higher (ESTIMATE 2) of the two percentages of FDs obtained on control displays (standard deviations in parentheses)*

	Kindergarteners				First-graders				Adults			
	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*
Etriangle	13.1 (10.1)	74.8 (10.3)	1.95 (0.30)	2.56 (2.20)	35.5 (14.7)	89.3 (11.2)	1.94 (0.66)	1.17 (0.54)	37.2 (21.8)	89.7 (5.9)	1.74 (0.40)	0.60 (0.35)
Ctriangle	2.6 (3.3)	88.1 (10.7)			3.3 (5.1)	83.1 (15.6)			1.6 (3.2)	88.3 (12.6)		
Cs	8.4 (8.8)	72.5 (16.7)			22.2 (12.8)	92.8 (6.4)			15.4 (10.0)	86.9 (11.5)		
Lower signal detection score obtained on either Ctriangle or Cs			2.16 (0.63)	3.33 (2.76)			2.26 (0.39)	0.88 (0.53)			2.37 (0.40)	1.20 (1.32)
ESTIMATE 1 TRIANGLE	+2.1 (7.5)				+10.0 (10.5)				+20.2 (18.8)			
ESTIMATE 2 TRIANGLE	+4.0 (6.2)				+13.3 (9.7)				+21.7 (20.0)			

E = experimental displays, including triangles and Ss.
C = control homogeneous displays, including either triangles or Ss.

Cs− and Ctriangle− are assumed to reflect simple misperceptions and are used as a baseline against which to compare any increase in conjunction errors. ESTIMATES 1 suggest that kindergarteners were the only group that did not report illusory conjunctions, and that these errors were more frequent in adults than in first-graders.

An analysis of variance was performed on FDs, taking into account both the percentage of FDs on experimental displays and the sum of the percentages of FDs on Cs− and Ctriangle− displays. It showed a significant interaction between display type and group ($F(2,31) = 4.59$, $p < .025$). The effect of display type (i.e., ESTIMATE 1) was significant both in first-graders ($F(1,11) = 10.16$, $p < .01$) and in adults ($F(1,11) = 12.72$, $p < .005$), but not in kindergarteners ($F < 1$). Testing the interaction between pairs of groups, the comparison was found significant between kindergarteners and adults ($F(1,20) = 7.45$, $p < .025$). Moreover, kindergarteners obtained less FDs than adults on experimental trials ($F(1,20) = 9.44$, $p < .01$), and did not differ from adults on control trials ($F(1,20) = 1.53$). For the comparison between kindergarteners and first-graders, the interaction fell short of significance ($F(1,20) = 3.69$, $p < .10$).

These results suggest that, contrary to our expectations, there may be some development of the preattentive separability of parts. Furthermore, given the fact that most kindergarteners (60%) did not display positive estimates, it is possible that children before approximately 6 years of age do not analyse the lines of triangles at the preattentive stage. However, while the baseline control value considered in ESTIMATE 1 is highly conservative and therefore appropriate when trying to prove that illusory conjunctions *do* occur, it must be considered as too conservative when dealing with the opposite hypothesis, namely that illusory conjunctions do *not* occur. Indeed, by adding the percentages of FDs obtained on the two types of control displays, one assumes that on any one experimental trial the subjects could score up to two FDs, which is an impossibility since they simply had to report the presence or absence of the target. Moreover, each control card has twice as many of a same type of item (either 10 Ss or 10 triangles) as an experimental card (5 Ss and 5 triangles). A less conservative value might, at first sight, be obtained by adding the raw FD scores obtained on each type of control display rather than the percentages of FDs. The average density of items being the same in each type of display, the total number of Ss and of triangles would be the same for control and experimental trials. However, the value calculated by adding the raw data is not appropriate to the present set of results. Most subjects (85% of the total group) misperceived Ss more often than triangles as dollar signs, and a majority of subjects (59% of the total group) misperceived *only* Ss as dollar signs. For the latter subjects, by adding the raw data, the maximum FDs on the 54 control trials could be only half (i.e., 27) the maximum on the 54 experimental trials. Thus, it seems more appropriate to the present results to take for each subject *the higher* of the two FD percentages obtained on the control displays, that is, on *either* Cs− *or* Ctriangle− as baseline control value. As can be seen in Table 1, the estimate of illusory conjunctions calculated in this last way (ESTIMATE 2) is less conservative than ESTIMATE 1.

Consistent with the definition of ESTIMATE 2, a further analysis of variance was performed on FD scores, taking this time as baseline control value the higher of the percentages of FDs obtained on either Cs− or Ctriangle−. This led basically to the same results as the previous analysis. The main differences are that ESTIMATE 2 fell short of significance in kindergarteners ($F(1,9) = 3.69$, $p < .10$), and that the interaction between display type and group came out significantly not only between kindergarteners and adults but also between kindergarteners and first-graders ($F(1,20) = 6.26$, $p < .025$). Thus, even when using a less conservative estimate, one still finds developmental effects. On the other hand, the more extreme hypothesis that kindergarteners lack preattentive separability of parts has to be considered with great caution. It is worth noting, however, that about half of the kindergarteners still give no evidence at all of using component parts of shapes in early processing (ESTIMATES 2 equal or inferior to 0%).

A significant estimate of illusory conjunctions may result either from a loss of discriminability in the experimental displays relative to the control displays, or from a bias in response criterion leading to respond "yes" more often on the former than on the latter trials, or from both factors. Of course, before one may interpret the group by display type interaction observed on FD scores as reflecting perceptual development, one must make sure that it does not simply result from a bias of kindergarteners towards responding "no" more often on the experimental trials than on the control trials relative to the other groups. The signal detection parameters d' and *Beta*, which take into account both FD and CD scores, were used to check whether illusory conjunctions took place either at the level of discriminability, or of response criterion, respectively, or at both levels. For each subject, two d' scores were considered: the d' score for experimental displays, and the lower of the two d' scores obtained on control displays (i.e., on either Cs or Ctriangle).[2] This procedure thus takes into account the type of control that is less discriminable for each particular subject. Mean d' scores were then calculated (see Table 1), and an analysis of variance was performed. On the basis of the hypothesis that the illusory conjunction effect reflects, at least partially, a loss of discriminability, it was predicted that the d' would be smaller for experimental than for control displays. This was the case only for adults ($F(1,11) = 9.9$, $p < .01$), not for kindergarteners and first-graders ($F < 1$ in both groups). The d' results are therefore consistent with the fact that most kindergarteners do not exhibit illusory conjunctions, and cast some doubts on the significant estimate obtained by first-graders. However, the interaction between group and display type was not significant ($F < 1$).

The *Beta* scores were calculated for each subject[2] by taking as baseline

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[2]Since d' and *Beta* scores go to infinity for observed probabilities of 1.0 and 0, arbitrarily chosen values replaced the 100 percent and 0 percent scores: 99 percent and 1 percent, respectively. This means that the absolute values for d' and *Beta* cannot be given much importance. However, the procedure used here allows comparisons of the different groups, display types and materials.

control value the lower of the two *Beta* values obtained on control displays, that is, the type of control showing the greatest bias to respond "yes" (see Table 1). The analysis of variance showed only a significant effect of group ($F(2,31) = 8.11, p < .005$). Kindergarteners obtained higher *Beta* scores than both first-graders ($F(1,20) = 8.67, p < .01$) and adults ($F(1,20) = 8.73, p < .01$); they thus respond "no" more often. But kindergarteners do not differ specifically on one type of display from the other groups: as a matter of fact, the interaction between group and display type was not significant ($F(2,31) = 1.22$).

In short, the results obtained on the *d'* and *Beta* scores do not allow a firm conclusion about the origins of the interaction between group and display type that was observed on the FDs. This interaction was reproduced with neither of the signal detection parameters. Therefore whether there is some development of part preattentive separability remains an open question. We will return to this issue in Experiments III and IV.

Experiment II: Illusory conjunctions of colour and form

In Experiment II, we examined whether there is some development of the preattentive processing of dimensions. Using dimensions which are obligatory attributes of stimuli rather than optional component parts might warrant different developmental patterns. In Experiment II, children were examined for the occurrence of illusory conjunctions of colour and form.

A pilot experiment was performed on the same children who participated in Experiment I. The pilot experiment used experimental displays containing green circles and red squares, and control displays containing either red squares and green triangles or green circles and blue squares.[3] The target was always red circle. The procedure and the calculation of the ESTIMATE 1 of illusory conjunctions were the same as in Experiment I. Both kindergarteners and first-graders obtained significant ESTIMATES 1 (mean: +9.1%, SD: 10.5; and +21.1%, SD: 16.5, respectively). However, the interaction between group and display type fell short of significance ($F(1,20) = 3.59, p < .10$), suggesting that there might be some development of dimensional separability. To ascertain more precisely whether or not the tendency to produce illusory conjunctions of colour and form develops, fresh and larger groups of children

[3]The heterogeneity of these control cards contrasted with the homogeneity of the control cards used in Experiment I. However, subjects were also tested at the end of the session with homogeneous control cards containing only red squares, and this change in the construction of the material was not found to produce a major effect on the occurrence of FDs.

(kindergarteners, first- and third-graders) and one group of adults were tested in Experiment II.

Method

Stimuli and procedure

Each display contained 10 items. Target-absent experimental displays (E−) contained 5 green circles and 5 red squares. Target-absent control displays contained either 5 red squares and 5 green triangles (*Cform−*) or 5 green circles and 5 blue squares (*Ccolour−*). The target was a red circle. Frequency of occurrence of the target, position of the target within the display, number of different arrangements for each type of display, total area of the display and background luminance were exactly the same as in Experiment I. The sizes of the individual items were chosen so that the different figures would have approximatively the same area and thus the same subjective size. The side of the squares subtended approximatively 1.3°, the diameter of the circles 1.4°, and the side of the equilateral triangles 1.5°. All the shapes were filled in with coloured inks on white cards.

The experiment was run using the same procedure as in Experiment I. Mean exposure durations were 99 ms for kindergarteners (from 62 to 187, SD: 34); 98 ms for first-graders (from 57 to 207, SD: 33); 72 ms for third-graders (from 54 to 154, SD: 26) and 42 ms for adults (from 28 to 61, SD: 9).

Subjects

The children were 24 kindergarteners, 9 girls and 15 boys, aged 4;11 to 6;4 yr (mean: 5;8 yr), 24 first-graders, 11 girls and 13 boys, aged 5;11 to 7;2 yr (mean: 6;7 yr), and 12 third-graders, 6 girls and 6 boys, aged 7;10 to 8;9 yr (mean: 8;5 yr). Half of the children in each group were tested at the beginning of the school year, the other half at the end. The school attended and children's socio-economic origin were similar to those of Experiment I. Eight additional children were discarded: two presented serious visual problems, two were suspected of mental retardation, and four had repeated the year. Adults were 12 undergraduate students, 6 women and 6 men, aged 19 to 24 yr, who were paid for their participation.

Results and discussion

Table 2 presents the mean FD and CD percentages for each type of display, and the mean estimates of illusory conjunctions, in each group. ESTIMATE 1, that is, the difference between the percentage of FDs made on E− trials and the sum of the percentages of FDs made on both types of control trials,

Table 2. *Experiment 2: Mean percentage of false detections (FD) and of correct target detections (CD), mean signal detection measures (d' and Beta) for each type of display, and mean estimates of illusory conjunctions in each group, taking as baseline control value either the sum (ESTIMATE 1) or the higher (ESTIMATE 2) of the two percentages of FDs obtained on control displays (standard deviations in parentheses)*

	Kindergarteners				First-graders				Third-graders				Adults			
	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*
E	30.8 (18.4)	70.7 (9.6)	1.20 (0.51)	1.46 (1.39)	34.8 (21.0)	76.9 (13.0)	1.33 (0.62)	1.29 (1.22)	31.8 (14.6)	74.5 (12.5)	1.24 (0.42)	1.00 (0.49)	51.1 (24.2)	84.8 (13.5)	1.17 (0.66)	0.61 (0.36)
Cform	8.0 (7.1)	84.7 (9.5)			7.7 (11.0)	83.3 (13.4)			6.1 (8.4)	90.3 (11.7)			14.0 (7.4)	96.6 (7.2)		
Ccolour	5.8 (7.7)	86.0 (14.9)			5.8 (11.9)	90.6 (6.7)			0.7 (1.5)	93.1 (6.8)			0.9 (2.1)	93.8 (8.5)		
Lower signal detection score obtained on either Cform or Ccolour			2.47 (0.86)	1.80 (2.15)			2.42 (0.71)	1.96 (2.01)			3.13 (0.46)	1.41 (1.89)			3.08 (0.36)	0.61 (1.00)
ESTIMATE 1	+17.0 (19.6)				+21.3 (16.5)				+25.0 (8.8)				+36.2 (22.7)			
ESTIMATE 2	+21.1 (17.2)				+23.0 (16.4)				+25.7 (9.1)				+37.1 (22.5)			

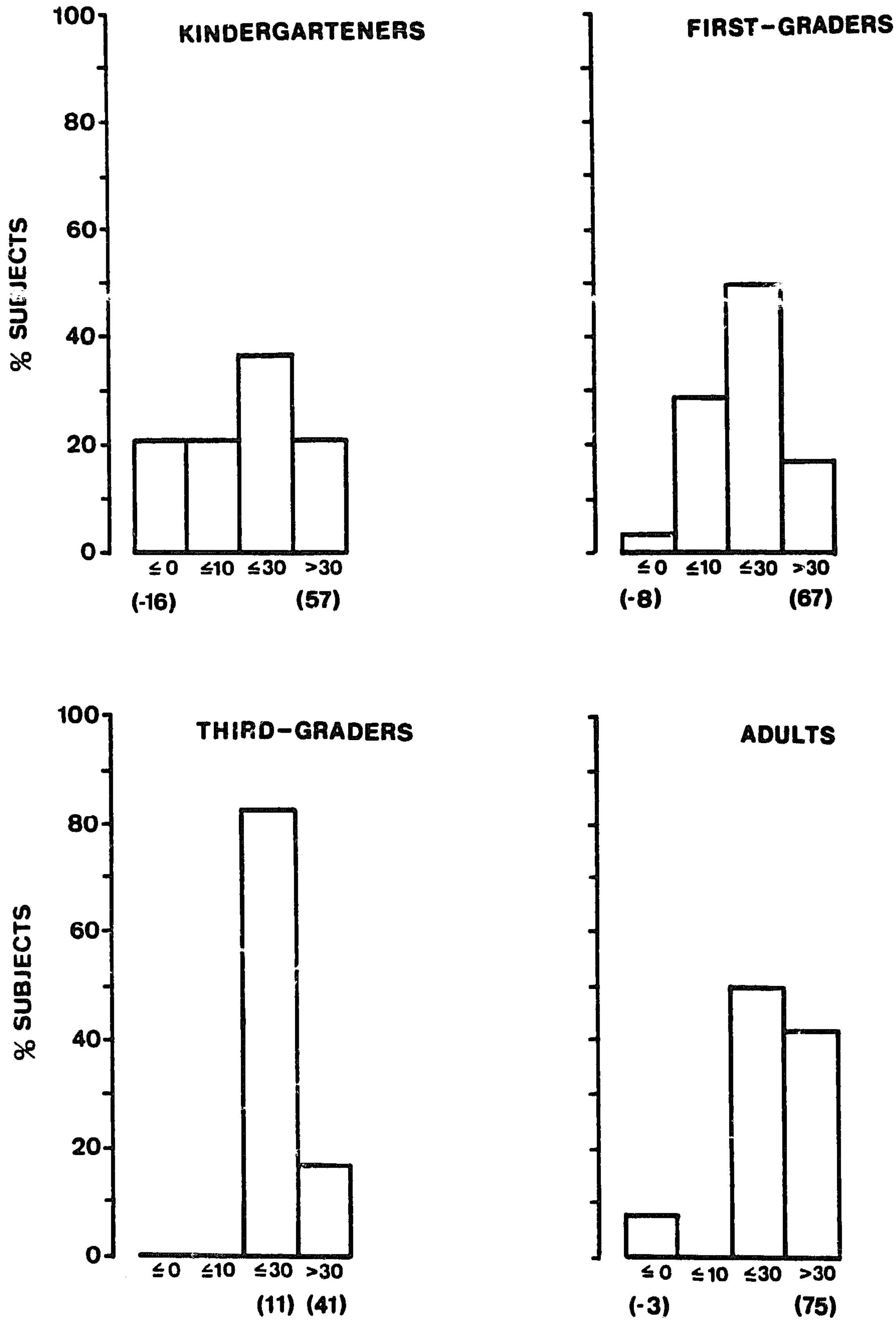
E = experimental displays, including red squares and green circles.
C = control displays, including either red squares and green triangles (Cform) or green circles and blue squares (Ccolour).

was significant in every group ($F(1,23) = 17.31$ and 38.29, $p < .0005$, for kindergarteners and first-graders, respectively, and $F(1,11) = 88.45$ and 27.84, $p < .0005$ for third-graders and adults, respectively). As in the pilot experiment, and using the most conservative estimate, even the youngest children exhibit illusory conjunctions of colour and form.

However, there was some indication of a developmental effect. It is apparent from Figure 2 (which presents the distribution of ESTIMATES 1 in each group) that there is some proportion of both kindergarteners and first-graders that obtained either a negative or a very low ESTIMATE 1. This is exceptional in older groups. Accordingly, the interaction between group and display type was marginally significant on ESTIMATE 1 ($F(3,60) = 3.04$, $p < .05$); on ESTIMATE 2, it fell short of significance ($F(3,60) = 2.44$, $p < .10$). Testing this interaction between particular pairs of groups, it was found significant at least at $p < .05$ for both the comparisons between kindergarteners and adults ($F(1,34) = 6.48$ for ESTIMATE 1 and 5.3 for ESTIMATE 2) and between first-graders and adults ($F(1,34) = 4.73$ for ESTIMATE 1 and 4.29 for ESTIMATE 2). Both kindergarteners and first-graders obtained less FDs than adults on experimental displays ($F(1,34) = 7.41$, $p < .025$ and 4.13, $p < .05$, respectively), and did not differ from adults on control displays, either with the baseline used in the calculation of ESTIMATE 1 ($F < 1$ for both groups) or with the baseline used in the calculation of ESTIMATE 2 ($F(1,34) = 2.18$ for kindergarteners and $F < 1$ for first-graders).

The d' and *Beta* scores were calculated for each subject in the same way as in the previous experiment (see Table 2). An analysis of variance on d' scores confirms that the effects of display type arise at a perceptual level: all groups obtained a lower d' score on experimental than on control displays ($F(1,23) = 40.78$ and 67.88, $p < .0005$, for kindergarteners and first-graders, respectively, and $F(1,11) = 158.55$ and 68.57, $p < .0005$, for third-graders and adults, respectively). However, there are also some indications of a developmental effect on d' scores. The difference between d' scores obtained on experimental *minus* control displays is less important in kindergarteners (−1.27) and first-graders (−1.09) than in third-graders (−1.89) and adults (−1.91). Accordingly, the group by display type interaction was significant ($F(3,68) = 4.67$, $p < .01$). Testing this interaction between particular pairs of groups, significant differences were found between kindergarteners and third-graders ($F(1,34) = 4.21$, $p < .05$), between first- and third-graders ($F(1,34) = 13.32$, $p < .001$), and between first-graders and adults ($F(1,34) = 10.7$, $p < .005$); however, the comparison between kindergarteners and adults fell short of significance ($F(1,34) = 3.89$, $p < .10$). The group by display type interaction observed in the analysis of d' scores was due to the fact that groups differ on *control* displays ($F(3,68) = 4.60$, $p < .01$), *not* on experimental ones ($F < 1$).

Figure 2. *Distributions of the ESTIMATES 1 of illusory conjunctions obtained in Experiment II, in each group. In parentheses: end-points of the distribution within a group.*



No significant main effect appeared in the analysis of variance on *Beta* scores. The comparisons between kindergarteners and adults and between first-graders and adults were significant ($F(1,34) = 5.28$, $p < .05$, and 5.94, $p < .025$, respectively), indicating a greater tendency of these children to respond "no". However, neither of the corresponding interactions with display type was significant ($F(1,34) < 1$ and $= 1.19$, respectively), and so group differences in response criterion cannot account for the developmental effect observed on the estimates.

Even young children seem to process colour and form separately at the preattentive stage. However, whether or not separability of these dimensions is less developed in kindergarteners and first-graders than in older subjects is not clear. It is worth noting that, although there was a significant group by display type interaction both on FDs and d' scores, the latter interaction was due to group differences on control displays, not on experimental ones. If the separate features are less accurately perceived by the children than by the adults, then the incidence of conjunctions should be expected to be smaller in the former group. This may be a trivial explanation of the fact that children obtained less illusory conjunctions than adults in the present experiment.

Experiment III: Distinguishing perceptual analysis and synthesis

The results of Experiments I and II reveal some developmental trends, but they cannot be unambiguously interpreted in terms of perceptual development. In Experiment I, even if adults were the only group to show an effect of display type on d' scores, the interaction with group on d' did not reach the significance level; in Experiment II, there was a significant group by display type interaction in the analysis of d' scores, but it was due to group differences on control displays, not on experimental displays. Perceptual differences across ages may be difficult to ascertain for a variety of reasons. For instance, exposure durations were far shorter for adults than for children, and the time needed for extracting the individual features seems to be different at different ages. Thus, a more indirect but perhaps more valid way of testing whether there is some perceptual development may be to compare subjects' performances on different materials, whose processing involves different abilities. Illusory dollar signs obtained from Ss and diagonals of triangles require both analysis of the triangles into separate segments and integration of the analysed parts into a coherent (even if illusory) object. But it is possible to manipulate the material in such a way that in one case conjunctions require prior analysis, and in another case they only require integration of unattached, spatially separate figures. Using spatially separate components of triangles (unattached diagonal lines and angles) and Ss, Treisman and Paterson (1984, Experiment 4) found that, in adults, triangles induce as many illusory dollar signs as unattached lines. In other words, for adults, segments of shapes are not more "sticky" at the preattentive stage than unconnected segments. The aim of Experiment III was to compare, at each particular age, the estimate of illusory dollar conjunctions obtained on the material of Experiment I to that obtained on the separate material designed by Treisman and Paterson (1984). Assuming that Treisman and Paterson's (1984) result in adults would be replicated here, an observation of more illusory conjunctions for unattached than for connected lines in young children would be consistent with the hypothesis of a development of perceptual analysis.

Method

Stimuli and procedure

Figure 1 presents examples of the displays used. As in Experiment I, the target was a tilted dollar sign. There were 5 types of target-absent displays. Experimental displays were of two types: Etriangle− contained 5 right-angle triangles and 5 tilted Ss, as in Experiment I; *Eseparate−* contained 5 tilted Ss and the spatially separated components (right angles and diagonal lines) of the triangles. Each pair of angle and diagonal line was counted as a single item. Target-absent control displays were of three types. As in Experiment I, Ctriangle− contained 10 triangles, and Cs− contained 10 tilted Ss. *Cseparate−* contained the spatially separate components of triangles, that is, 10 pairs of angles and diagonal lines. Diagonals and Ss were always tilted on the right. Frequency of occurrence of the target and position of the target within the display were the same as in Experiment I. Fourteen different arrangements were constructed for each type of experimental− displays, 6 for each type of experimental+ displays, 7 for each type of control− displays and 3 for each type of control+ displays.

Material construction and procedure were similar to Experiment I, but with the following exceptions. The session was longer, about 45 min for adults and 60 min for children. It included four blocks, one for practice and three experimental, of 70 trials each. Children received the 10 types of displays as practice (reinforced) trials first at 3 s, next at 1 s. Mean exposure durations during the experimental phase were 59 ms for adults (from 40 to 92, SD: 15); 173 ms for kindergarteners (from 114 to 222, SD: 33); and 123 ms for first-graders (from 81 to 168, SD: 33).

Subjects

The adults were 24 undergraduate students, 14 women and 10 men, aged 17 to 24 yr, who were paid for their participation. The children were 12 kindergarteners, 6 girls and 6 boys, aged 4;10 to 5;10 yr (mean: 5;3 yr), and 12 first-graders, 7 girls and 5 boys, aged 5;11 to 6;9 yr (mean: 6;7 yr). They were tested in the first half of the school year. The school attended and the socio-economic origin were comparable to those of previous experiments.

Results and discussion

Table 3 presents the mean FD and CD percentages for each type of display, and the mean estimates of illusory conjunctions for each type of material, in each group. Initially two aspects of the results are worth noting: as in Experiment I, the triangle material discloses a developmental effect on the estimates, but this effect is at least strongly reduced with the separate material. A former analysis of variance was performed according to the principle of the traditional and most conservative ESTIMATE 1, that is, taking as control score the sum of the percentages of FDs obtained on the two types of control displays. It showed a significant three-factor interaction of material, display type and group ($F(2,45) = 6.55, p < .005$). The effect of display type, that is, ESTIMATE 1, was significant in each group for separate lines ($F(1,11) = 6.7, p < .05$; $F(1,11) = 13.6, p < .005$, and $F(1,23) = 49.31, p < .0005$ for kindergarteners, first-graders and adults, respectively). For triangles it was significant in first-graders ($F(1,11) = 5.56, p < .05$) and in adults ($F(1,23) = 77.06, p < .0005$), but not in kindergarteners ($F < 1$). Therefore the result of Experiment I showing no significant ESTIMATE 1 in kindergarteners was replicated. However, this is true only when the occurrence of illusory conjunctions requires figure analysis. This conclusion is reinforced by the fact that the interaction between material and display type was highly significant in kindergarteners ($F(1,11) = 21.45, p < .001$), marginally significant in first-graders ($F(1,11) = 6.36, p < .05$), but fell short of significance in adults ($F(1,23) = 3.83, p < .10$).

However, the notion that kindergarteners have no preattentive analysis of figure lines is not supported by the ESTIMATES 2 (see Table 3). The analysis of variance performed on FDs scores according to the principle of this estimate showed a marginally significant effect of display type for triangles in kindergarteners ($F(1,11) = 5.56, p < .05$). Thus, when using a less conservative estimate, even the youngest children seem as a group to experience illusory conjunctions of parts of closed shapes. But this effect should not conceal the fact that many kindergarteners (42%) still give no evidence at all of using component parts of triangles in early processing (ESTIMATE 2

Table 3. *Experiment 3: Mean percentage of false detections (FD) and of correct target detections (CD), mean signal detection measures (d' and Beta) for each type of display, and mean estimates of illusory conjunctions for each material, in each group, taking as baseline control value either the sum (ESTIMATE 1) or the higher (ESTIMATE 2) of the two percentages of FDs obtained on control displays (standard deviations in parentheses)*

	Kindergarteners				First-graders				Adults			
	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*
Etriangle	39.6	74.1	1.14	1.32	22.9	64.5	1.25	1.68	39.5	82.2	1.32	0.75
	(16.9)	(18.6)	(0.67)	(2.08)	(15.9)	(12.7)	(0.40)	(0.92)	(15.9)	(12.5)	(0.45)	(0.45)
Ctriangle	23.2	73.3			4.9	77.9			2.4	86.2		
	(17.7)	(20.0)			(5.9)	(17.6)			(4.3)	(8.5)		
Cs	20.7	74.3			10.3	76.2			11.5	80.1		
	(13.7)	(15.1)			(9.6)	(11.7)			(8.1)	(15.5)		
Lower signal detection score obtained on either Ctriangle or Cs			1.35	1.01			2.09	3.65			2.26	2.06
			(0.70)	(0.99)			(0.40)	(4.30)			(0.62)	(2.44)
ESTIMATE 1 TRIANGLE	− 4.3				+ 7.7				+25.6			
	(21.0)				(10.8)				(14.0)			
ESTIMATE 2 TRIANGLE	+10.5				+11.4				+27.7			
	(13.6)				(11.0)				(13.5)			
Eseparate	58.9	73.2	0.60	0.76	34.2	56.9	0.66	1.26	50.8	82.2	1.01	0.68
	(19.7)	(20.6)	(0.64)	(0.41)	(22.5)	(18.1)	(0.58)	(0.39)	(19.4)	(11.6)	(0.43)	(0.29)
Cseparate	17.2	85.3			6.4	75.2			8.0	86.9		
	(11.8)	(15.1)			(7.9)	(9.1)			(7.7)	(8.6)		
Cs	20.7	74.3			10.3	76.2			11.5	80.1		
	(13.7)	(15.1)			(9.6)	(11.7)			(8.1)	(15.5)		
Lower signal detection score obtained on either Cseparate or Cs			1.62	0.94			2.13	4.30			2.08	1.57
			(0.73)	(1.05)			(0.40)	(5.23)			(0.51)	(2.24)

	Kindergarteners				First-graders				Adults			
	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*
ESTIMATE 1 SEPARATE	+21.0 (27.0)				+17.5 (15.4)				+31.3 (21.4)			
ESTIMATE 2 SEPARATE	+35.8 (20.1)				+22.0 (17.7)				+36.3 (19.9)			

E = experimental displays, including Ss and either triangles (Etriangle) or separate angles and diagonal lines (Eseparate).
C = control homogeneous displays, including either Ss, or triangles, or separate angles and diagonal lines.

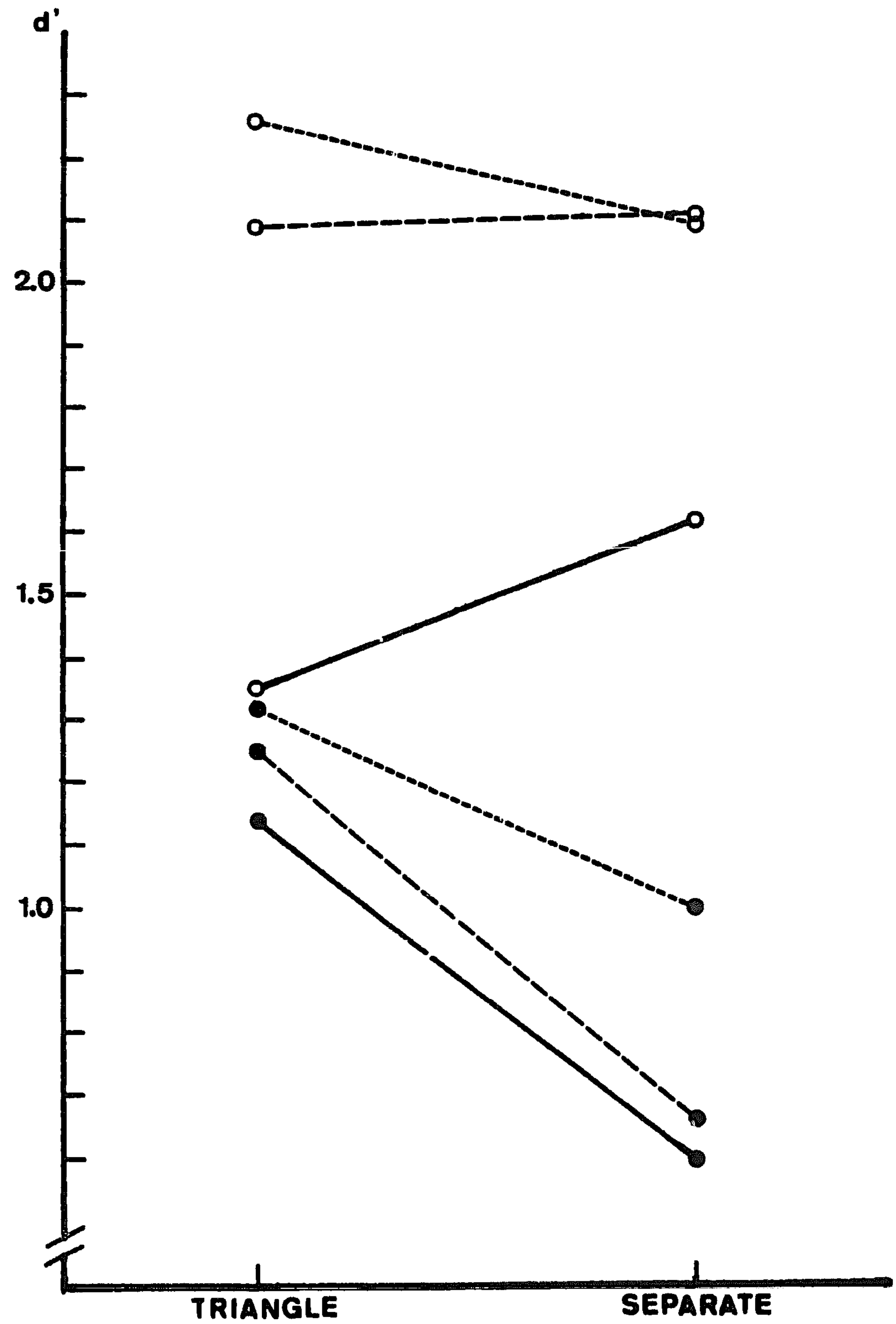
equal or inferior to 0%). This was true in only 8 percent of the first-graders and never occurred in adults. However, for separate lines all subjects, including kindergarteners, had positive ESTIMATES 2. Moreover, even when using ESTIMATE 2, the three-factor interaction was found significant ($F(2,45) = 6.5, p < .005$). Analysis of this interaction (to avoid redundancy, only the results of the analysis on ESTIMATE 2 will be presented henceforth) revealed that the interaction between group and display type was significant for triangles ($F(2,45) = 9.38, p < .0005$), but not for separate lines ($F(2,45) = 2.23$). And further analysis revealed that, for triangles, the interaction was significant when adults were compared to either kindergarteners ($F(1,34) = 12.16, p < .005$) or first-graders ($F(1,34) = 12.33, p < .005$), but there was no interaction between kindergarteners and first-graders ($F < 1$).

The present experiment confirms the developmental effect on the preattentive separability of parts of figures also found in Experiment I. However, a potential problem arises from the fact that in this experiment, contrary to what was observed on FDs in Experiment I, for the material including triangles kindergarteners differed from adults on *control* ($F(1,34) = 17.69, p < .005$) and not on experimental displays ($F < 1$). The staircase procedure which was aimed at matching between-group performances on control trials seems to have failed in this case. Again the problem is that the interaction between group and display type obtained for kindergarteners and adults on triangles might simply result from an artefact: if children perceive the features less accurately than adults, they will obtain less conjunctions of these features. Before examining this problem further, it is worth noting that it does not occur with first-graders: as is apparent in Table 3, they differed from adults on Etriangle– only ($F(1,34) = 8.22, p < .01$), not on control displays ($F < 1$). Therefore it seems likely that there is some developmental tendency to make illusory conjunctions of parts of shapes from first-graders to adults.

The overall pattern of kindergarteners' results offers an objection against interpreting the developmental effect as an artefact. Like first-graders, kindergarteners obtained a significant interaction between material and display type due to the fact that they obtained fewer FDs on Etriangle− than on Eseparate− ($F(1,11) = 28.94$, $p < .0005$ and 17.87, $p < .005$, for kindergarteners and first-graders, respectively), without displaying an important difference between the two respective control for triangles and separate lines ($F(1,11) = 3.91$, $p < .10$, and < 1, for kindergarteners and first-graders, respectively). Moreover, kindergarteners also obtained significantly more FDs than adults on control trials for separate lines ($F(1,34) = 6.33$, $p < .025$). Thus, the relatively low level of kindergarteners' FDs on Etriangle− in comparison to their FDs on the respective controls (Cs− and/or Ctriangle−) does not represent an upper limit to the occurrence of FDs. It reflects the fact that kindergarteners are much less prone to make illusory conjunctions with the material including triangles than with the one including unattached lines.

The d' and *Beta* scores were calculated for each subject in the same way as in the previous experiments (see Table 3 and Figure 3). The results of the analysis of variance performed on d' scores mirror the main findings observed on FDs. The three-way interaction of group, material and display type was significant ($F(2,45) = 4.48$, $p < .025$). Analysis of this interaction reveals that there is a significant difference between adults and either kindergarteners ($F(1,34) = 9.32$, $p < .005$) or first-graders ($F(1,34) = 4.45$, $p < .05$), but not between kindergarteners and first-graders ($F < 1$). The interaction between group and display type was significant only for triangles ($F(2,45) = 4.84$, $p < .025$), not for separate lines ($F(2,45) = 1.8$). With triangles, only kindergarteners did not display lower d' scores on experimental than on control displays ($F < 1$, whereas $F(1,11) = 45.99$, $p < .0005$ and $F(1,23) = 38.99$, $p < .0005$ for first-graders and adults, respectively). With separate lines, the effect of display type was significant in every group ($F(1,11) = 50.9$ and 68.22, $p < .0005$, for kindergarteners and first-graders, respectively, and $F(1,23) = 50.24$ for adults). The difference between the d' scores obtained on experimental displays and the d' scores obtained on control displays was larger for separate lines than for triangles in kindergarteners (−1 02 *versus* −0.21) and in first-graders (−1.47 *versus* −0.84), and for each of these groups the interaction between material and display type was significant ($F(1,11) = 12.81$, $p < .005$ and $= 6.2$, $p < .05$, respectively). This was not the case in adults (−1.07 *versus* −0.94, $F(1,23) = 1.42$). In children, the significant material by display type interaction is due to differences on the d' scores obtained on experimental displays ($F(1,11) = 8.84$ and 8.08, $p < .025$ for kindergarteners and first-graders, respectively), not to differences on the d' scores obtained on control displays ($F(1,11) = 2.08$ and < 1, for kindergarteners and first-graders, respectively). However, as in the previous experiments, the interpretation of the group differences is less clear: for the material including triangles, children differ from adults on control displays ($F(2,45) = 9.05$, $p < .001$), not on experimental displays ($F < 1$). But the important point is that the material differences observed on FDs in the two groups of children is fully confirmed by the analysis of the *d'* scores.

Figure 3. *Mean* d' *scores obtained in Experiment 3 by kindergarteners (——), first-graders (–––) and adults (- - -) on experimental (●) and control (○) displays.*



The analysis of variance performed on *Beta* scores showed a marginally significant three-factor interaction of group, material and display type ($F(2,45) = 3.72$, $p < .05$). In both first-graders and adults, there was a slight bias towards saying "yes" more often on Eseparate− than on the respective control (either Cs− or Cseparate−) displays ($F(1,11) = 4.23$, $p < .10$, and $F(1,23) = 3.79$, $p < .10$), and towards saying "yes" more often on Etriangle− than on the respective control (either Cs− or Ctriangle−) displays ($F(1,11) = 3.21$, $p < .10$, and $F(1,23) = 7.92$, $p < .025$). Since, in these groups, we also observed display type effects on d' scores, one may conclude that both the perceptual and the response stages concurred to the production of illusory conjunctions in first-graders and adults. However, the effect of display type was not significant in kindergarteners ($F < 1$ for both materials). There was some suggestion of a group by display type interaction when kindergarteners were compared to either first-graders ($F(1,22) = 3.86$, $p < .10$) or adults ($F(1,34) = 3.08$, $p < .10$). However, the three-way interaction was significant only for the comparison between first-graders and adults ($F(1,34) = 9.0$, $p < .005$). Therefore, response bias cannot explain all the effects observed on FDs. In particular, it is not possible to explain within-group material differences observed on FDs only in terms of response bias. In the analysis of *Beta* scores, it was only in first-graders that the interaction between material and display type fell short of significance ($F(1,11) = 4.71$, $p < .10$), showing a bias advantaging unattached lines. Since the same interaction was significant in the analysis of d' scores, it may be concluded that both the perceptual stage and the decision stage have concurred to the material effect displayed by first-graders. Kindergarteners did not show such a criterion bias ($F < 1$). Besides, it is puzzling that kindergarteners' *Beta* scores were much lower in the present experiment than in Experiment I. It seems likely that the presence of unattached lines trials eliciting illusory conjunctions in these subjects has increased their tendency to respond "yes".

In short, Treisman and Paterson's (1984) finding that adults are not influenced by whether the lines to be conjoined are or not parts of a figure was replicated. However, children made less illusory conjunctions when parts have to be detached from other components of a shape than with unattached lines. Even if group differences are themselves difficult to interpret, since they are due to differences on control rather than on experimental displays, within-group material effects were unambiguous in young children both on FD and on d' scores. The present experiment strongly reinforces the idea that there is a development of part separability at the preattentive stage of processing. At the same time, it shows that young children are as capable of perceptual synthesis of separate parts as adults.

Experiment IV: Analysis of closed versus open shapes

In Experiment III children, unlike adults, displayed a very clear material effect. The next question is why, in children, diagonal lines of triangles contribute less frequently than unattached lines to illusory conjunctions. It could be the case that children analyse shapes into component lines only when these are marked by line ends (*terminators*, in Julesz's 1980 terminology). Or it could be that closed shapes like triangles present other preattentive available features that are more salient for children than their component lines, for example, the emergent property of *closure* (see Treisman & Paterson, 1984, Experiment 5; Treisman & Souther, 1985). Experiment IV was aimed at investigating whether the material effect displayed by children in Experiment III occurs only with closed figures. It used arrows as open figures in addition to the previous materials. Treisman and Paterson (1984, Experiment 4) have shown that, in adults, parts of arrows exhibit the same degree of separability as parts of triangles, and as spatially separate, unattached lines.

Method

Stimuli and procedure

As in Experiments I and III, the target was a tilted dollar sign. There were seven types of target-absent displays (see Figure 1). Experimental displays were of three types. Etriangle− and Eseparate− were the same as in Experiment III. The third type of experimental displays, *Earrow−*, contained 5 Ss and 5 arrows facing right, that is, with diagonal lines in the same orientation as in triangles. Target-absent control displays were of four types. Ctriangle−, Cseparate− and Cs− were the same as in Experiment III. *Carrow−* contained 10 arrows. Construction of items and of the different arrangements for each type of display were the same as in Experiment III, except that 14 different arrangements were added for Earrow−, 6 for Earrow+, 7 for Carrow− and 3 for Carrow+.

The procedure was similar to Experiments I and III but with the following exceptions. The session was longer (60 min for adults and 75 min for children). Children received the 14 different types of displays as practice (reinforced) trials first at 3 s, next at 1 s. For all subjects, the session included four blocks of 100 trials each. Initial exposure durations for the experimental phase were the same as in Experiments I and III, but the staircase procedure was changed so that non-detections of real target on experimental displays were also taken into account. This was done in order to obtain higher correct detections scores than in the former experiments on parts of shapes. Mean exposure durations during the experimental phase were 178 ms for kindergarteners (from 111 to 230, SD: 32); and 166 ms for first-graders (from 112 to 214, SD: 31).

Subjects

The children were 16 kindergarteners, 8 girls and 8 boys, aged 5;3 to 6;1 yr (mean: 5;8 yr), and 16 first-graders, 5 girls and 11 boys, aged 6;2 to 7;1 yr (mean 6;8 yr). All the children were tested during the second half of the school year. The school attended and the socio-economic origin were comparable to those of previous experiments. Two additional subjects were eliminated, one because his mean percentage of CDs across conditions was very low (around 50%), and the other because he never made FDs.

Results and discussion

Table 4 presents the mean FD and CD percentages for each type of display, as well as the estimates of illusory conjunctions. The most apparent aspect of the results is that the arrow material elicits estimates that are intermediate between those obtained with triangles and with separate lines. The analysis of variance performed on FDs according to the principle of ESTIMATE 1 showed a significant interaction of material and display type ($F(2,60) = 21.58$, $p < .0005$). This interaction was significant, not only for the comparisons between triangles and separate lines ($F(1,30) = 40.41$, $p < .0005$), arrows and separate lines ($F(1,30) = 12.23$, $p < .005$), but also for the comparison between triangles and arrows ($F(1,30) = 9.9$, $p < .005$). It is worth noting that the material by display type interaction is due to the fact that there were differences between materials on experimental displays ($F(2,60) = 29.19$, $p < .0005$), not on control displays ($F < 1$). In particular, children made more FDs on Eseparate− than on both Earrow− ($F(1,30) = 14.53$, $p < .001$) and Etriangle− ($F(1,30) = 54.85$, $p < .0005$), and more on Earrow− than on Etriangle− ($F(1,30) = 17.05$, $p < .0005$), without showing any difference between the respective control displays ($F(1,30) < 1$, $= 1.31$, and $= 1.8$, respectively). Further analysis of the interaction shows that the effect of display type, that is, ESTIMATE 1, was significant for both separate lines ($F(1,30) = 46.43$, $p < .0005$) and arrows ($F(1,30) = 8.31$, $p < .01$), but not for triangles ($F < 1$). The interaction with group was not significant, but some results are interesting to note. With triangles, neither group obtained a significant ESTIMATE 1 ($F(1,15) < 1$ and $= 2.33$, for kindergarteners and first-graders, respectively). With separate lines, both groups obtained highly significant ESTIMATES 1 ($F(1,15) = 18.27$, $p < .001$ and $= 30.92$, $p < .0005$, respectively). And with arrows, ESTIMATE 1 was significant in first-graders

($F(1,15) = 11.96$, $p < .005$) but not in kindergarteners ($F(1,15) = 2,17$). Therefore, it appears once again that for children component parts of triangles do not contribute as much as unattached lines to the production of illusory conjunctions. In addition, arrows seem to be more decomposable than triangles, but their components would not be represented as independently of one another as unattached lines.

Table 4. *Experiment 4: Mean percentage of false detections (FD) and of correct target detections (CD), mean signal detection measures (*d'* and* Beta*) for each type of display, and mean estimates of illusory conjunctions for each material, in each group, taking as baseline control value either the sum (ESTIMATE 1) or the higher (ESTIMATE 2) of the two percentages of FDs obtained on control displays (standard deviations in parentheses)*

	Kindergarteners				First-graders			
	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*
Etriangle	23.1 (14.2)	84.8 (10.6)	2.00 (0.56)	1.20 (1.67)	13.5 (8.4)	80.2 (10.0)	2.11 (0.53)	1.99 (2.12)
Ctriangle	8.1 (7.3)	86.9 (12.4)			3.7 (4.7)	80.1 (14.7)		
Cs	14.1 (14.7)	74.6 (12.1)			6.6 (7.1)	80.7 (13.9)		
Lower signal detection score obtained on either Ctriangle or Cs			2.01 (0.72)	2.95 (4.59)			2.30 (0.45)	3.56 (3.99)
ESTIMATE 1 TRIANGLE	+ 0.9 (20.2)				+ 3.2 (8.1)			
ESTIMATE 2 TRIANGLE	+ 7.5 (17.9)				+ 5.7 (7.0)			
Eseparate	44.9 (19.5)	80.3 (12.2)	1.09 (0.67)	0.79 (0.40)	34.0 (16.9)	76.6 (13.8)	1.28 (0.51)	1.72 (3.30)
Cseparate	9.6 (9.5)	82.8 (14.0)			5.3 (4.0)	82.1 (11.6)		
Cs	14.1 (14.7)	74.6 (12.1)			6.6 (7.1)	80.7 (13.9)		

Table 4 (continued)

	Kindergarteners				First-graders			
	FD	CD	*d'*	*Beta*	FD	CD	*d'*	*Beta*
Lower signal detection score obtained on either Cseparate or Cs			1.96 (0.72)	3.45 (4.78)			2.40 (0.56)	2.80 (3.52)
ESTIMATE 1 SEPARATE	+21.2 (19.2)				+22.1 (15.4)			
ESTIMATE 2 SEPARATE	+29.7 (19.4)				+25.9 (15.3)			
Earrow	32.7 (15.5)	84.3 (11.4)	1.64 (0.73)	0.71 (0.42)	21.5 (9.0)	75.8 (12.4)	1.61 (0.37)	1.30 (1.00)
Carrow	10.3 (7.9)	80.7 (12.8)			5.3 (6.3)	86.2 (15.0)		
Cs	14.1 (14.7)	74.6 (12.1)			6.6 (7.1)	80.7 (13.9)		
Lower signal detection score obtained on either Carrow or Cs			1.89 (0.65)	3.00 (4.28)			2.46 (0.55)	2.41 (3.39)
ESTIMATE 1 ARROW	+ 8.3 (21.9)				+ 9.6 (11.3)			
ESTIMATE 2 ARROW	+16.2 (20.0)				+13.0 (8.6)			

E = experimental displays, including Ss and either triangles (Etriangle) or separate angles and lines (Eseparate), or arrows (Earrow).
C = control homogeneous displays, including either Ss, or triangles, or separate angles and lines, or arrows.

The analysis of variance performed on FDs according to the principle of ESTIMATE 2 showed exactly the same findings with regard to the main effects and interactions as the previous analysis. There were only two local differences. ESTIMATE 2 was significant in kindergarteners for arrows ($F(1,15) = 9.82$, $p < .01$) and in first-graders for triangles ($F(1,15) = 9.81$, $p < .01$). For the latter material, the estimate obtained by kindergarteners was still not significant ($F(1,15) = 2.67$). Thus, even when using a less conservative estimate, there was no strong evidence in the present experiment that kindergarteners experience illusory conjunctions of parts of triangles.

The d' and *Beta* scores were calculated for each subject in the same way as in the previous experiments (see Table 4). The analysis of variance performed on the d' scores led basically to the same results as those obtained on FDs (see also Figure 4). It showed a significant interaction of material and display type ($F(2,60) = 14.46, p < .0005$). This interaction was significant for each pair of materials ($F(1,30) = 28.18$, $p < .0005$ for triangles *versus* separate lines; $F(1,30) = 6.06$, $p < .025$ for arrows *versus* separate lines; and $F(1,30) = 9.18$, $p < .001$ for triangles *versus* arrows). As in the analysis of FDs, it is worth noting that the material by display type interaction is due to the fact that there were differences between materials on experimental displays ($F(2,60) = 18.18, p < .0005$), not on control displays ($F < 1$). Children obtained lower d' scores on Eseparate− than on both Earrow− ($F(1,30) = 6.45$, $p < .025$) and Etriangle− ($F(1,30) = 36.18$, $p < .0005$), and obtained lower d' scores on Earrow− than on Etriangle− ($F(1,30) = 15.95$, $p < .0005$), without showing any difference between the respective control displays (F always < 1). Further analysis of the interaction shows that experimental displays led to lower d' scores than control displays for separate lines ($F(1,30) = 30.23$, $p < .0005$) and for arrows ($F(1,30) = 17.37$, $p < .0005$), but not for triangles ($F < 1$). As in the analysis of FDs, even if no interaction with group came out to be significant, it is interesting to note that with triangles the effect of display type was significant in neither group ($F(1,15) < 1$ and $= 1.03$, for kindergarteners and first-graders, respectively); with separate lines it was significant in both groups ($F(1,15) = 8.45, p < .025$ and $= 30.52$, $p < .0005$, respectively); and with arrows it was significant in first-graders ($F(1,15) = 23.76$, $p < .0005$) but not in kindergarteners ($F(1,15) = 1.55$). Therefore the d' analysis strongly supports the idea that the significant estimates of illusory conjunctions and the differences between materials observed in the present experiment reflect perceptual phenomena.

The analysis of variance performed on *Beta* scores showed a significant effect of display type ($F(1,30) = 5.78, p < .025$), reflecting the fact that there was a bias towards saying "yes" more often on experimental than on control trials. Therefore illusory conjunctions observed in the present experiment are a result of both response bias and perceptual discriminability. There was, however, no interaction with group or material (F always < 1). Thus, as in Experiment III, response bias alone cannot account for the material differences observed on the FDs.

Correlations between age and the ESTIMATES 1 of illusory conjunctions for either arrows or triangles are consistently higher for the kindergarten than for the first-grade group (see Table 5). This suggests that the emergence of preattentive separability of parts of figures depends crucially on age within a relatively narrow age window, but that later development may extend over

Figure 4. *Mean* d′ *scores obtained in Experiment 4 by kindergarteners (——) and first-graders (---) on experimental (●) and control (○) displays.*

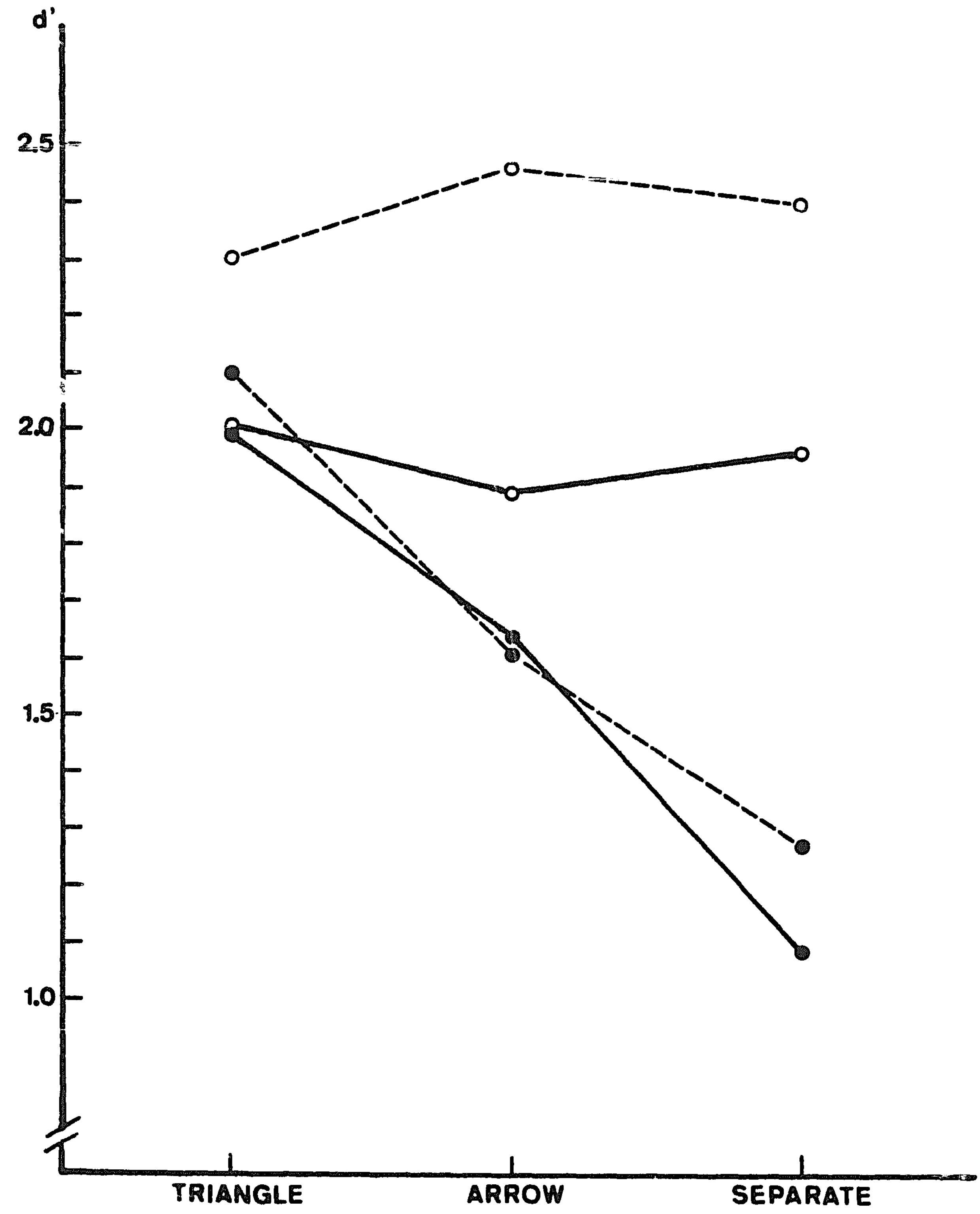


Table 5. *Correlations between age and the ESTIMATES 1 of illusory conjunctions obtained on the different materials, and intercorrelations of ESTIMATES 1 obtained on these different materials with each other, within each group of children. Within each cell, top row: Experiment III; bottom row: Experiment IV*

	Kindergarteners		
	Separate lines	Arrows	Triangles
Age	.24		.46*
	.27	.58***	.53**
Separate			.74****
lines		.39	.60****
Arrows			
			.76*****
	First-graders		
	Separate lines	Arrows	Triangles
Age	.11		−.16
	.34	−.002	−.34
Separate			.58**
lines		.35	.16
Arrows			
			.55***

Correlations significant at:
* $p = .10$
** $p < .05$
*** $p < .02$
**** $p < .01$
***** $p < .001$

a few years. However, consistent with the idea that part integration is already fully developed at the earliest age tested here, there was no significant correlation between age and the ESTIMATES 1 obtained on separate lines.

All the correlations between ESTIMATES 1 for the different materials are positive and some of them are significant (see Table 5). Examination of the individual patterns of ESTIMATES 1 for the different materials reveals that only one subject (out of 32) obtained a positive estimate on triangles without also displaying a positive estimate on separate lines. Only two subjects obtained a positive estimate on arrows without also displaying a positive estimate on separate lines. And only one subject displayed a positive estimate on triangles without also displaying a positive estimate on arrows. Thus, the exceptions to a sequential pattern of development are very rare.

Two results of the present experiment are consistent with Experiment III. First, highly significant estimates of illusory conjunctions were obtained by either group of subjects for separate lines. Second, kindergarteners do not exhibit a significant ESTIMATE 1 of illusory conjunctions with parts of closed shapes like triangles. As in Experiment I, but contrary to Experiment III, kindergarteners did not reach a significant estimate on triangles when using the less conservative ESTIMATE 2. Also contrary to Experiment III, the mean ESTIMATE 1 obtained by first-graders on triangles was not significant; however, their mean ESTIMATE 2 was significant. Exact reasons for these discrepancies are unknown, but they could suggest that separability of parts of closed shapes begins to develop but is still not well established in this childhood period.

The main question of the present experiment concerns the ability of parts of open figures to promote illusory conjunctions in young children. The highly significant difference obtained between arrows and separate lines in either group suggests that parts of open figures are more "sticky" than unattached lines for young children. Especially for kindergarteners, parts of either open or closed figures seem to be less separable than for adults, who are not influenced by whether the parts to be conjoined are included in a figure or not (see Experiment III and Treisman & Paterson, 1984). However, open figures do not prevent illusory conjunctions in children as much as closed shapes. With arrows, first-graders obtained significant estimates, kindergarteners obtained a significant ESTIMATE 2, and both groups obtained higher estimates than with triangles. The use of component parts could develop more rapidly for open than for closed shapes. Moreover, the pattern of individual results suggests that the analysis of open shapes might precede for each subject the analysis of closed ones.

General discussion

Almost all current conceptualizations of visual processing (Beck, 1982; Julesz & Bergen, 1983; Marr, 1982; Treisman & Gelade, 1980) agree with the need to introduce a broad distinction between "early" and "late" visual processing. Moreover, many theories propose that the initial perceptual stage consists of a decomposition of the input by a set of independent, feature-analysing systems, even if they disagree about the exact nature of the extracted features (see discussion in Treisman, 1985). Since the initial stages of processing are supposed to be unavailable to conscious awareness, they could only be studied by using relatively indirect methods. Indirect evidence that objects are initially represented by separate attributes, and not as indivisible gestalts, is provided by the illusory conjunctions phenomenon. Assuming both that this phenomenon taps an early stage of processing, and that this stage is relatively independent of development (Treisman, 1986a), one should expect to find illusory conjunctions in young children as well as in adults.

However, the results of the present series of experiments do not fully confirm this prediction. When using the method of Treisman and Paterson (1984) for estimating illusory conjunctions, kindergarteners failed to obtain a significant estimate of illusory conjunctions of parts of triangles in three experiments, and first-graders did not obtain it in the last experiment. Of course, these results do not imply that young children do not experience illusory conjunctions at all. The estimates on parts of triangles which were calculated using a less conservative method were all either significant or just fell short of significance, except for kindergarteners in Experiment IV. Most of these effects were, however, not supported by the analysis of *d'* scores. The only substantial evidence for illusory conjunctions of parts of triangles was obtained by the group of adults (Experiments I and III) and by the first-graders in Experiment III, who displayed both significant estimates and an effect of display type on *d'* scores. One can only conclude that the separability of the component lines of triangles is not fully developed in kindergarteners and first-graders.

The developmental effect observed on false detection scores, however, is sometimes difficult to interpret: examining the *d'* scores, we observed either that the group by display type interaction was not replicated (Experiment I), or that it was due to differences between groups on control displays, not on experimental ones (Experiment III). But the material by display type interaction observed on children's false detection scores (Experiments III and IV) reinforces the conclusion that there is a developmental effect. For the comparison between triangles and unattached, spatially separate lines, this interaction was found to be significant in young children in both the analyses of false detections and of *d'* scores, whereas for adults it was not. This shows that for children, contrary to adults, diagonals of triangles are more "sticky" than unattached diagonal lines. The fact that illusory conjunctions are present in children to roughly the same extent as in adults when no figure analysis is required, that is, when the illusion was created by a mere conjunction of unattached lines, also argues against several alternative explanations of the developmental effect observed on materials requiring figure analysis. First, it rules out the possibility that this effect is due to differences between groups in procedure or in target familiarity. Second, it refutes the idea that children might be unable to synthesize, rather than to analyse, visual information. In fact children seem to be as capable as adults to integrate parts that are separate in the display. Unattached parts are probably registered by the same kind of parallel process, and, when attention is overloaded, wrongly combine with the same frequency in both populations.

Experiment IV suggests that the relative incapacity of young children to analyse shapes into parts depends on the characteristics of the shape itself. For children, parts of open shapes like arrows are more "sticky" than unattached lines, but not so "sticky" as parts of closed shapes like triangles. In addition, the d' scores were consistent with the estimates and indicate that the analysis of arrows into angles and lines significantly occur in first-graders, but not yet in kindergarteners. With arrows, kindergarteners failed to show substantial evidence for illusory conjunctions, which they obtained with the spatially separate angles and lines, and first-graders did obtain illusory conjunctions, which they failed to show with triangles. Even though generalization on the basis of two particular shapes may be premature, these developmental trends and the analysis of individual scores both suggest that decomposition of open shapes constitutes an early step towards analysis of closed shapes. Further research will have to assess whether it is the presence of an emergent feature like closure or the absence of line terminators that differentiates closed from open shapes in the development of preattentive analysis.

A difference in the analysis of closed *versus* open shapes in young children has also been found using a part-verification task designed by Palmer (1977) and adapted to child testing (Kolinsky, Morais, Content, & Cary, 1987). The subjects were asked to find three-segment parts within six-segment figures. The ability to find deeply embedded segments was absent in kindergarteners and in a high proportion of first-graders, but was well developed in second-graders. Examination of results item by item revealed that young children's performance was adversely affected when some of the target segments belonged to a closed part, in each case a triangle, within the figure. This task and the task of target detection used here presumably tap different levels of processing. While finding a part in a figure probably involves some postperceptual analytic capacity, detecting a figure does not necessarily involve any kind of conscious analysis of its components. But the similarity between the two sets of results may lead one to speculate that the development of postperceptual analysis crucially depends on analytical unconscious processes that are still developing in young children.

Contrary to what was observed on parts of shapes, Experiment II showed that illusory conjunctions of colour and form do occur in all age groups. Signal detection analyses supported the view that these effects arise at a perceptual stage of processing rather than as a consequence of decision criteria. This result, which indicates preattentive separability of colour and form in young children, is consistent with the observations that dimensions do play some role in young children's behaviour, even if they are not directly accessible for classification purposes (e.g., Kemler, 1982a; 1982b; Kemler & Smith, 1979; Smith, 1979, 1984; Smith & Kemler, 1978). It is also consistent with the finding obtained with the habituation technique, that infants as young as 4 months perceive dimensions separately. Of course, preattentive separability of dimensions could be present very early, and nevertheless continue to develop with age. Therefore the developmental hypothesis cannot be dismissed on the basis of the present work, but it receives no support, either. The interaction between group and display type on *d'* scores was not due to a group difference on the displays that may elicit illusory conjunctions, that is, the experimental displays, but on the control ones.

The fact that a majority of kindergarteners experienced illusory conjunctions of colour and form whereas most of them did not experience illusory conjunctions of parts of closed shapes may appear surprising, since illusory conjunctions of colour and form also concern closed shapes. However, it seems reasonable to assume that such illusory conjunctions do not necessarily imply, at least in children, the breaking of closed shapes, but might result from interchanging colours and whole patterns. Young children would treat separately colours and whole shapes before they treat separately component parts of shapes. The problem then is to interpret adults' results. Since adults obtained illusory conjunctions both between parts of shapes and between whole shapes and colours, one possibility already suggested by Treisman and Souther (1986) to account for the particular case of conjunctions of either letters or parts of letters is that in adults the conjunction process may be applied at different scales. Alternatively, it could be that coloured shapes are actually analysed into colours and parts by adults. The occurrence of illusory shapes, in addition to illusory conjunctions of colour and shape, could be tested by using either a free report task, or a dual target-detection task. Whatever the solution of this problem, the fact that the separability of colour and form develops earlier than the separability of parts may be related to the fact that these dimensions are obligatory attributes of visual objects, whereas parts are optional. Moreover, dimensions characterize the parts as well as the whole. Further research will have to assess, of course, whether the present results are not restricted to the processing of colour, which is an especially salient cue for both children and adults (Bornstein, 1981; Garner, 1983).

The fact that a majority of kindergarteners saw illusory conjunctions of colour and form must be confronted with the results obtained by young children on the same dimensions in classification tasks. It does not conflict with the observation of interference effects in speeded constrained classification, since this effect may only reflect the inability of young children to selectively attend to one dimension by filtering out the other. The development of selective attention to dimensions probably lags the development of the ability to perceive the dimensional structure of the stimulus. On the other hand, the present results seem to conflict with the observations that young children both use global similarity relations in free classification and display redundancy gains in the correlated condition of speeded constrained classification. Indeed, the redundancy introduced in this condition served to increase the judged distance between stimuli if one uses a "global", non-dimensional Euclidean metric (see, for example, Handel & Imai, 1972). We suggest, however, that the apparent conflict reflects the fact that the evidence obtained in classification tasks refers to a later stage of processing than that obtained in the present task. The "global" representations of young children would in fact be constructed by a set of independent analysers. Therefore children and adults might not differ in the way their conscious percepts are elaborated, but in their capacity to either carry out postperceptual analysis on their perceptual experience, or to access early analytic codes. As for the parts of shapes, separability of dimensions would develop first at early stages of processing, then at more central ones.

The developmental effects observed in the present series of experiments for the preattentive processing of component parts of shapes have been interpreted so far as reflecting the development of the initial analytical stage of visual perception. If this interpretation is correct, one has to consider what is the nature of the initial processing in young children. It could be that, before the development of an analytical stage, children directly match a global representation of the input against a stored template. Alternatively, it could be that young children process the input in an analytical way like adults, but that the attributes they extract from it are not the same. For instance, rather than decomposing a triangle into angles and lines, young children might apprehend the relationships between the angles or some other emergent feature. Indeed, it is possible that children's analytic abilities are hampered by some capacity limitation. If there is a limit of one or two features per shape, emergent features may be more salient than lines and may therefore compete effectively with their processing. At present, these hypotheses are entirely speculative. Moreover, there is still another possible interpretation. It is based on the idea that the occurrence of illusory conjunctions does not provide evidence on the very initial stage of perceptual processing, but rather on a later stage that nevertheless precedes the one investigated by classification tasks. As already suggested by Neisser (1967), it may be a simplification to assume that perceptual processing includes only two, one preattentive and one attentional, stages of processing.

A recent study on conjunction phenomena in adults (Houck & Hoffman, 1986) strongly supports the view that different experimental procedures may tap different stages of early processing. These authors showed that an orientation-contingent colour after-effect (cf. McCollough, 1965) is independent both of the display size and of whether the adaptation stimuli are presented inside or outside of the focus of attention. Colour and orientation appear to conjoin preattentively. However, in the same study, these attributes appeared to be separable in a search task, since the search times for the conjunctions of these attributes varied as a function of display size. Therefore preattentive vision might include both feature-integrated and feature-separated processing. Furthermore, neurobiological findings do not always support the view that the brain is functioning only on the basis of feature-selective cells: for example, some colour-selective cells are also sensitive to shape features like orientation (cf. the discussion presented by Marrocco, 1986). The apparent discrepancy between adaptation and neurobiological data, which suggest that the visual system may treat conjunctions of features at a very early stage, and the greater part of behavioural data, which indicate that conjunctions of properties are not preattentively available, for example, for search purpose or texture segregation (see Treisman, 1986a, for a review), argues against the idea of a single preattentive stage. A possible framework for interpreting the present results is thus one in which preattentive processes are themselves subdivided into several stages of processing. Illusory conjunctions may not arise directly from the earliest visual representations, even if it is an "early" phenomenon. In conclusion, there is some development of the perceptual analysis of shapes, but whether it concerns the very initial stage of visual processing remains an open question.

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Résumé

Dans des conditions ne permettant pas une focalisation de l'attention, l'apparition de conjonctions illusoires (erreurs dans la recombinaison des traits de différents objets) est l'indice d'un codage séparé des traits dans une phase précoce du traitement. L'apparition des conjonctions illusoires a été utilisée afin de déterminer si les enfants agés de 5 à 8 ans effectuaient une analyse pré-attentive des dimensions (couleur et forme) et des segments de formes (triangles et flèches). On trouve l'indication d'une analyse pré-attentive même chez les enfants les plus jeunes pour la couleur et la forme, mais pas pour les segments de forme. Alors que les effets de développement atteignent à peine la signification, l'examen des capacités susceptibles d'influencer le phénomène de conjonctions illusoires suggère qu'à ce stade pré-attentif du traitement les enfants peuvent intégrer les segments séparés spatialement, mais ne sont pas capables d'analyser complètement les segments connectés.