Finding parts within figures: a developmental study

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Received 12 August 1986, in revised form 14 April 1987

Reprinted from PERCEPTION a Pion publication

Perception, 1987, volume 16, pages 399-407

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Abstract. Preschool children, primary school children, and unschooled adults were tested on the part-probe task designed by Palmer. Relatively high scores were obtained with all groups on parts which had a 'good' relationship with the figure. However, the ability to find more deeply embedded segments was not present in the preschool children or in the unschooled adults. This indicates that the processes of postperceptual analysis necessary to find a part in a figure are neither built-in nor the consequence of mere cognitive growth, but depend on the instruction or experience usually provided in school. Such processes should not be confused with those that lead to form perception. Inspection of the part–figure pairs and of the corresponding detection scores suggests the importance of several stimulus properties.

1 Introduction

One interesting idea in cognitive theory is the distinction between perceptual and postperceptual, or secondary, analysis. Perception is usually identified with the recognition of objects and events. Most of the time these are recognized at their basic, that is, most functionally useful, level (Rosch et al 1976). We recognize something as a sheep, or a car, or a house; "we do not record explicitly the shape of the ear of a sheep, or whether any of the parts of a car are triangular, or how many windows there are in one's house" (Pinker 1984, page 55). These properties are not phenomenologically salient ["phenomenological salience is accessibility *without* sustained inspection" (Fodor 1983, page 96)], but we can, if we want, recover them by sustained inspection. We will call perceptual the processes that lead in a nonintentional way to the most immediate conscious representation of some stimulus, and postperceptual those processes that operate on such representations and may or may not be employed, depending on the goal.

The need to distinguish between perceptual and postperceptual processes is quite apparent in the field of language (see, for instance, Foss and Swinney 1973; Swinney 1982). For example, phonetic decoding in speech comprehension can be regarded as a perceptual process, but judging the presence of a phoneme target in speech involves postperceptual processes in addition to perceptual ones. Strengthening the theoretical relevance of this distinction, it was observed that illiterates display evidence of phonetic feature analysis in a speech recognition task, as do literates (Morais et al 1987), but, unlike literates, they frequently fail to detect phoneme targets (Morais et al 1986). The perceptual/postperceptual distinction has been less clearly noted, if not sometimes overlooked, in nonlinguistic visual processing. However, it should be equally relevant. Perceptual processes in vision have been investigated in many studies by means of tasks that require postperceptual judgments. We do not deny that these tasks have provided us with information about perceptual processes, but would stress that the possibility that the findings reflect postperceptual processes rather than perceptual ones should be checked in each case by a rigorous analysis of the cognitive demands of the task.

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It is not sufficient to evaluate the cognitive demands of so-called perceptual tasks on the basis of introspection or common sense. The same component of a task could appear as natural, obvious, and effortless to us, the experimenters, and to our usual subjects, undergraduate students, but as difficult or impracticable to less sophisticated people. For example, the detection of a phoneme or a syllable in a spoken word appears as a task that could provide information about the units used in speech perception. Shorter reaction times in the detection of syllables relative to the detection of phonemes have been interpreted as indicating the priority of syllable identification in perceptual processing. However, this interpretation rests on the implicit and undemonstrated assumption that no more time is needed to recover phonemes than syllables from the output of the perceptual processor (cf the discussion in Morais 1985). In this context it is worth noting that illiterate adults are generally unable to analyze speech explicitly into phonetic or phonemic segments (Morais et al 1979, 1986), but are successful in syllable manipulation tasks. They are also poorer at checking sentences for the occurrence of a word beginning with a stop consonant than with a syllable (Morais et al 1986). Even though alphabetic literacy elicits the ability to analyze speech into phonemes with a high degree of accuracy, it is not unreasonable to believe that phonemes remain of less direct postperceptual access than syllables.

Among the tasks that have been used to study visual perception, one, the part-probe task, presents an obvious analogy with phoneme and syllable monitoring. In both tasks the subject is given a probe and required to search for it in another stimulus. Both require postperceptual processes in the sense that it is not sufficient to perceive the probe and the stimulus that contains the probe but it is also necessary to analyze the latter with the aim of recovering the former. The fact that both phoneme monitoring and visual part-probe tasks imply postperceptual processes, the fact that adult illiterates are very poor subjects in phoneme monitoring, and the fact that the part-probe task has been used for a long time in visual perception led us to examine the performance of unsophisticated subjects on the part-probe task.

The part-probe task is a classic task in visual perception. It was employed by Gottschaldt (1926) to support the Gestalt assumption that the use of configurational properties in perception does not depend on prior exposure. More recently, Palmer (1977) has used the part-probe task to validate his model of perceptual representation as a hierarchical structure. This model, as we understand it, does not concern the processes by which perceptual representations are elaborated. In the part-probe task the subject is asked to inspect his perceptual representation of some figure or object. The subject probably has no access to interlevel representations.

The main idea underlying Palmer's model is that the perceptual representation of a complex object should be hierarchically structured (cf also Sutherland 1968; Reed 1973). The figure of a man, for instance, would be defined as head, trunk, and limbs in certain relationships, each of these units having its own structure. According to Palmer, there might be "numerous levels of representation in the form of hierarchical networks. At each level in a hierarchy, structural units are defined both holistically as a set of global properties and atomically as an organized set of parts. These parts are the structural units at the next-lower level in the hierarchy" (page 442). One essential aspect of Palmer's model is the hypothesis of selective organization, that is, that not all possible subsets of elements in a figure are encoded as structural units. Palmer developed an algebraic function to specify the 'goodness' of the relationships between the segments of complex line figures such as those presented in figure 1 and thus to predict which subsets of elements form structural units in the perceptual representation of the figure. The algebraic function integrates values along each of several Gestalt principles of grouping. Measures derived from the algebraic function were tested by asking subjects to divide figures into their 'natural parts' and by getting the subjects to rate the goodness of parts within figures. Subjects' parsings and rates conformed to the predictions. In a part-probe task the subjects were then required to decide whether or not the segments of a part-probe were contained within a presented figure. The results showed that positive responses to figure-part pairs of high goodness value were much faster than to pairs of medium or low value. The process of part verification can thus not be only one of template (point-by-point) or of segment-by-segment comparison. The 'best' parts in the figures used by Palmer are likely to be encoded as structural units in the perceptual representations of the figures. Part verification would begin at this level. In case of mismatch, sequential verification of subparts would be necessary at a lower level in the hierarchy. To Palmer, the simplest general type of process capable of accounting for the results of the part verification task "is one in which good parts can be matched holistically and in parallel, while bad parts must be matched componentially and serially" (page 470).

Our hypothesis was that the kind of componential analysis that is involved in Palmer's test is a sophisticated cognitive ability which does not develop spontaneously but requires a great deal of experience. If so, one might suspect that children before or at the beginning of school life and unschooled adults would both be able to detect the presence of parts with a good relationship with the figure, but would give a large number of omissions when presented with bad parts. For this reason we did not ask the subjects to respond quickly but used accuracy as a measure rather than, as Palmer did, speed. In Palmer's experiment the error rates for the set of stimuli we used in the present study (the 'same-figure' stimuli) were very low (between 5% and 10%) and did not seem to be a function of the goodness of parts within figures. They were most likely related to the speed demands of the task.

Four groups of children were tested, two from kindergarten and two from primary school. Two groups of adults who had not attended school in childhood for social reasons were also tested; one included completely illiterate people, the other people who had learned to read and write as adults in special classes. The latter could provide evidence that the analytic abilities involved in reading contribute to the development of the ability to analyze visual material.

2 Method

2.1 *Subjects*

Four groups of sixteen children were drawn from state schools in Brussels, Belgium. Each included eight girls and eight boys. One group (2-KG) consisted of children in the second level of kindergarten: their ages varied between 50 and 59 months (mean: 4 years 7 months). Another group (3-KG) consisted of children in the third (that is, last) level of kindergarten: their ages varied between 60 and 70 months (mean: 5 years 4 months). The two remaining groups of children were drawn from first-grade to second-grade classes in primary schools. The first-graders (1-G) were aged 72 to 84 months (mean: 6 years 7 months); the second-graders (2-G) 88 to 103 months (mean: 7 years 10 months). All these groups were tested during the second part of the school year, between March and June.

Two groups of unschooled adults, twelve illiterates (IA) and twelve ex-illiterates (ex-IA), were found in Portugal, in neighbouring areas of Porto and Lisbon. For social reasons people in these groups had never attended normal school. At the time of testing most of them were working on farming activities or as servants. The illiterates, eight women and four men, were aged 39 to 66 years (mean: 53 years 8 months). The ex-illiterates, eleven women and one man, were people of the same social origin and about the same age, on average, as the illiterates, but had attended evening literacy classes as adults. They were aged 44 to 69 years (mean: 51 years 1 month).

2.2 *Stimuli*

The stimuli (see figure 1) were a subset of the Palmer (1977) part-probe task material. As in that study, we used three ranks of 'goodness' values: high (H), medium (M), and low (L). The goodness of each part-figure pair was computed by Palmer (1977) with the algebraic function described in section 1. Six six-segment figures were presented five times each. Parts were always composed of three segments. For a particular figure there were three positive pairs (one for each level of goodness) and two negative ones. Negative pairs were those in which the part was not contained within the figure. As in Palmer's study, they were formed by pairing each figure with parts of another figure. One half of the negative pairs included parts that shared only one segment with the figure, the other half included parts that shared two segments with the figure. There was a total of eighteen positive pairs and twelve negative ones. Three positive pairs and two negative ones were used in a short training period. Three additional pairs of figure and part were used as examples. Each stimulus was drawn in black ink on a 3 × 3 dot matrix. The matrix, 2 cm high and 2 cm wide, was centered on a white card. Separate cards were used for parts and figures.

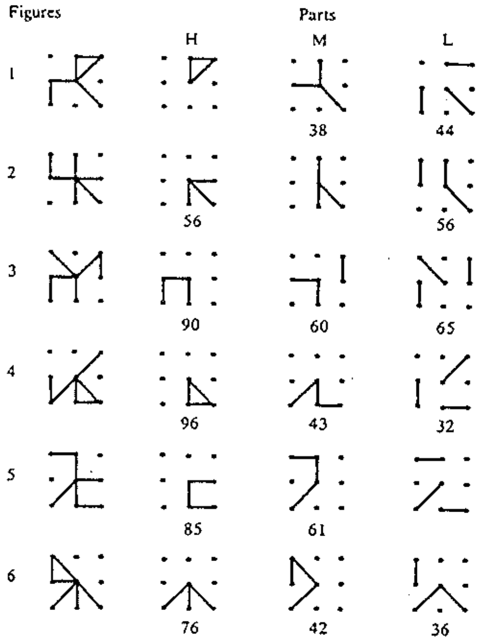

Figure 1. Total set of positive part-figure pairs used in the experiment (adapted from Palmer 1977). Three levels of 'goodness' are represented: H, high; M, medium; and L, low. The score below each part indicates the percentage correct responses obtained by the total number of subjects (eighty-eight) for each particular pair.

2.3 *Procedure*

On each trial the experimenter first showed the six-segment figure and then the three-segment part. Both cards remained in view on a table in front of the subject till an answer was given. The subject had to say whether he or she could "find the little part within the big drawing". The task was presented as a hiding game, in which somebody had sometimes hidden the little part in the big drawing, the game being to find if the

part was present even when hidden. The instructions emphasized the nonfigurative nature of the drawings.

The session began with three examples, two M pairs and one negative pair. Then five pairs, three positive (one for each level of goodness) and two negative, were presented for a short training phase. During the training phase the responses were verbally approved or corrected. For the examples and the training trials the experimenter used a transparent sheet on which the three-segment part was drawn in a dashed line. The transparent sheet was first superimposed on the part card, showing that they were identical. Next it was superimposed on the figure card, and the experimenter called the subject's attention to the exact match between the three segments drawn on the transparent sheet and the corresponding segments in the figure. There were twenty-five experimental trials, fifteen positives (five for each goodness value) and ten negatives, presented without feedback. All subjects received the trials in the same order, established to avoid the occurrence of more than three consecutive identical levels of goodness and more than three consecutive identical responses (negative or positive). The whole session took about half an hour.

3 Results

Table 1 shows the mean number of correct positive responses according to goodness level for each group and the mean number of correct negative responses. An analysis of variance on positive trials showed significant effects of group ($F_{5,82} = 8.49$, $p < 0.0005$) and goodness level ($F_{2,164} = 75.81$, $p < 0.0005$), and a significant group × goodness interaction ($F_{10,164} = 2.76$, $p < 0.005$). Groups were compared to each other for overall performance on positive trials. Scheffé tests showed that comparisons involving second-graders were all significant at the 0.0005 level. The only other significant comparison was the one between first-graders and illiterate adults ($p < 0.05$).

The split in performance between H pairs on the one hand and M and L pairs on the other hand is supported by the significant differences between H and M pairs and between H and L pairs (Scheffé tests significant at $p < 0.0005$), and the lack of significant differences between M and L pairs. The effect of goodness was significant for each group. Figure 2 shows clearly that second-graders differ from the other groups mainly on M and L trials: only second-graders performed above chance on these trials.

Table 1. Mean number of correct responses for each type of part-figure pair for each group of subjects. Standard deviations are given in parentheses. H high, M medium, and L low level of 'goodness'.

Subject	Positive pairs			Negative pairs (10)
	H (5)[a]	M (5)	L (5)	
Kindergarten, 2nd level	3.25	2.19	2.31	5.56
	(1.09)	(1.42)	(1.04)	(1.73)
Kindergarten, 3rd level	3.56	2.31	1.94	7.06
	(1.17)	(1.16)	(1.35)	(2.73)
First grade	4.50	2.38	2.19	9.56
	(0.50)	(1.17)	(2.21)	(0.61)
Second grade	4.88	3.69	4.25	9.44
	(0.33)	(1.21)	(0.90)	(0.86)
Illiterate adults	4.00	1.67	1.17	7.75
	(1.29)	(1.55)	(0.80)	(1.09)
Ex-illiterate adults	3.83	2.17	1.67	7.92
	(0.99)	(1.40)	(1.31)	(1.75)

[a] Number of pairs.

The pattern of results suggests that performance is critically dependent on instruction normally provided in the first years of primary school. Unschooled adults did not differ from preschool children on trials requiring analytic processing. Moreover, more detailed analysis indicates that first-graders could be in a transition period. First, they were better than preschool children (and even than ex-illiterate adults) on H pairs, and better than all other unschooled groups on negative pairs. Second, their distribution of performance on L pairs appears to be bimodal: seven subjects performed at zero level, whereas five subjects succeeded on all pairs. Thus, about half of the subjects were totally unable to detect the L parts, and rejected their presence categorically, whereas about a third of the subjects performed perfectly on those trials.

The percentage of correct detections for each positive pair is presented in table 2. Analysis of performance by item provides information on the major sources of difficulty. Detection performance averaged over all the subjects did not correspond exactly to the goodness categories predicted by Palmer's algebraic function, nor to the reaction times and goodness ratings he obtained with the same stimulus material on university students (see table 2). One trial of high goodness value (F2,H) was performed with an unexpectedly low level of accuracy, whereas one trial of medium value (F5,M) and two trials of low value (F3,L) and (F2,L) were performed with relatively high levels of accuracy. The factors, or their weight, that influence part detection performance may not be exactly the same in university students as in children and unsophisticated people.

Inspection of the part-figure pairs and of the corresponding detection scores (see table 2 and figure 1) obtained in the present study suggests the relevance of the following properties.

Property 1: Some, but not all, of the target segments belong to a closed part within the figure. This property would affect detection negatively. Figures 1, 4, and 6 contain a triangle. This may explain why trials F4,L, F6,L, F1,M, F6,M, F4,M, and F1,L yielded the lowest scores (fewer than 50% corret detections), and why trials F2,L, F3,M, F5,M, and F3,L, in which the property is absent, yielded higher scores (from 56% to 65% correct detections). An analysis of variance, comparing the six trials having property 1 with the four that do not have this property, showed a significant

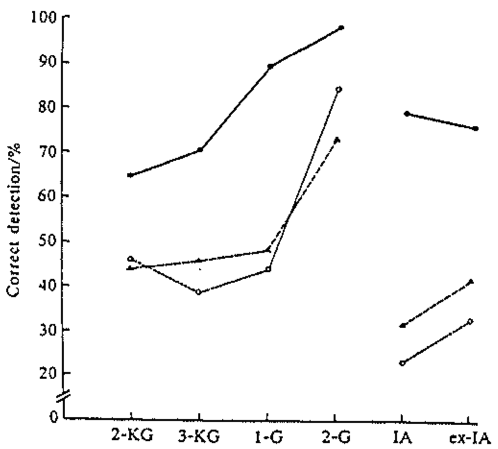

Figure 2. Percentage of correct detections for each group of subjects on positive pairs of high (•—•), medium (▲- - -▲), and low (o---o) 'goodness' value. 2-KG, preschool children in the second level of kindergarten; 3-KG, preschool children in the third level of kindergarten; 1-G, first-grade primary school children; 2-G, second-grade primary school children; IA, illiterate adults; ex-IA, unschooled adults who had learnt to read and write at an adult age.

effect of the property ($F_{1,82}$ = 53.33, $p < 0.0005$) and no significant interaction with group.

Property 2: The target has only one point of contact with the rest of the figure and they can be separated by a single axis. This property would facilitate detection. It is present in all H trials.

Property 3: The target contains one or two segments that belong to a straight line in the figure. This property, which would render detection more difficult, may explain the hierarchy of performance among the H trials. In fact, two segments of the part in F2,H (56% detections) belong to straight lines. In addition, trials F6,H and F5,H, in which one segment belongs to a straight line, yielded lower performance (76% and 85% detections, respectively) than trials F3,H (90%) and F4,H (96%), in which the property is absent. An analysis of variance was performed within the H trials to compare the three pairs having property 3 with the two pairs that do not have it. It showed a significant effect of the property ($F_{1,82}$ = 39.64, $p < 0.0005$) and a small but significant interaction with group ($F_{5,82}$ = 2.6, $p < 0.05$). The effect of property 3 was significant in second-level ($F_{1,15}$ = 10.24, $p < 0.01$) and third-level ($F_{1,15}$ = 13.6, $p < 0.005$) preschool children, first-graders ($F_{1,15}$ = 15.0, $p < 0.005$), and illiterate adults ($F_{1,11}$ = 8.27, $p < 0.025$). The same tendency is observed but did not attain significance in ex-illiterates and second-graders. In the latter group, the absence of effect is linked to the fact that only the item F2,H was not succeeded by all the subjects.

Finally, analysis of variance on negative pairs showed a group effect ($F_{5,82}$ = 12.58, $p < 0.0005$), but group dissociation does not correspond to that found for positive pairs. Second-level preschool children showed the poorest performance on negative pairs and seem to have used a guessing strategy throughout the test. Third-level preschool children and unschooled adults performed at about the same level, but were still inferior to first- and second-graders, who performed almost perfectly.

Table 2. Percentage of correct detections in each group of subjects for each (once-presented) positive part-figure pair. Pairs are listed according to figure number (F) and goodness level (H, high; M, medium; L, low) and presented in increasing order of the performance estimated over the entire sample. The second and third columns give the mean goodness ratings (on a scale of 1 to 10) and mean reaction times (RT) obtained by Palmer (1977).

Pair	Goodness rating	RT/ms	Correct detection/%						
			2-KG[a]	3-KG	1-G	2-G	IA	ex-IA	total
F4,L	1.31	1757	31	25	38	75	0	8	32
F6,L	2.87	1107	44	13	31	75	25	25	36
F1,M	3.37	1342	25	13	50	81	25	25	38
F6,M	4.19	1902	25	56	25	50	42	58	42
F4,M	4.50	1574	56	50	38	56	17	33	43
F1,L	1.69	1924	31	50	44	88	17	25	44
F2,H	8.94	904	31	31	56	88	75	58	56
F2,L	2.31	1525	63	50	50	94	25	42	56
F3,M	3.13	1834	38	69	50	94	50	58	60
F5,M	7.75	1343	75	44	75	88	33	42	61
F3,L	1.31	1763	63	56	56	94	50	67	65
F6,H	9.06	839	56	63	94	100	58	83	76
F5,H	8.81	713	75	75	100	100	83	75	85
F3,H	8.69	994	81	88	100	100	92	75	90
F4,H	9.25	885	88	100	100	100	92	92	96
Number of subjects, *N*			16	16	16	16	12	12	88

[a] 2-KG, kindergarten, second level; 3-KG, kindergarten, third level; 1-G, primary school, first grade; 2-G, primary school, second grade; IA, illiterate adults; ex-IA, unschooled adults who had learnt to read and write at an adult age.

4 Discussion

To find a part in a figure is more than a perceptual task. It requires perception of the figure, but also cognitive or postperceptual processes of componential analysis. Two types of componential analysis can thus be distinguished on a conceptual basis: preattentive, obligatory, analysis of the components of a figure, which leads to the perception of the figure, and attentional, optional, task-dependent analysis of the percept of the figure into its components. It is not unreasonable to assume that all the subjects in our study perceived the figures presented and that they perceived them by means of processes that include the first kind of componential analysis. What we have shown in this study is that some of the groups tested lacked the second kind to some extent. The ability to decompose a figure in order to find embedded segments is not present in preschool children and does not develop spontaneously as a consequence of cognitive maturation. The preschool children and about half of the first-graders were unable to detect such segments, whereas second-graders could do it most of the time. Moreover, unschooled adults performed roughly like preschool children. Thus, the componential analysis of visual forms requires more than the simple experience of objects in the natural world. Instruction provided in the first school years probably includes activities that render the emergence of this ability necessary. Obviously, the observation of emergence of the ability of visual componential analysis at the second grade of primary school should not be considered as a general rule. If school activities are the crucial factor the school grade at which the ability emerges may differ from country to country, from school to school, and even from class to class.

The exact nature of these activities cannot be ascertained in the present study. However, this study was designed to examine the possibility that training on one particular analytic ability facilitates the emergence of other analytic abilities (in other words, that componential analysis of one type of material may be transferred to other types of material). Ex-illiterate unschooled adults, but not illiterate ones, have developed the ability to analyze speech explicitly into phonological components. Although we did not test our subjects on speech analysis, previous work (Morais et al 1979, 1986) has clearly shown this difference in ability in the same kinds of populations. In our task, ex-illiterates and illiterates performed in the same way. The componential analysis of speech does not therefore generalize, at least immediately, to the componential analysis of visual forms. The fact that ex-illiterates were as weak as illiterates in our study contradicts the objection that the illiterates' inability might simply be due to a lower level of general intelligence or motivation. Ex-illiterates, that is, people who have not attended school in childhood and who have learnt to read and write as adults, are presumably intelligent and have active brains; they have often had to sit for examinations and, indeed, have experience in decoding graphic representations.

Each group was, on average, better on trials involving part-figure relationships of high goodness value than those of medium or low value. However, closer examination revealed several discrepancies between our results and the goodness categories predicted by Palmer (1977). We have presented three properties that could account for our results. Note that comparable properties were already considered among Palmer's dimensions of association between two segments. The discrepancies between our results and Palmer's goodness categories may be linked to the fact that the weight of parameters in the goodness equation is not the most suitable criterion with which to describe the performance of our subjects. It should also be noted that the goodness ratings and reaction times obtained by Palmer (1977) with the 'same-figure' material on university students do not seem to be influenced by properties 1 (closedness) and 3 (continuity). It is therefore unsophisticated subjects for whom the particular salience of closed or continuous parts within the figure renders componential analysis difficult.

Palmer's (1977) model describes the perceptual representation of a figure as a hierarchical network of structural units. If we interpret our data in the framework of this model we may be tempted to suggest that the units contained in the perceptual representation of a figure are those which are detected by unschooled people. The parts undetected by these subjects would not be encoded as units; to detect them would require at least the acquisition of a process of segment-by-segment verification.

Unschooled adults would thus be the ideal subjects with whom to examine the structure of perceptual representations since they are not endowed, as schooled adults are, with sophisticated analytic powers. But such perceptual representations must be understood as the final products of perceptual processing, that is, the contents of perceptual experience. The possibility that our final perceptual representations involve only 'gestalts' is not incompatible with the existence of intermediate representations based on a decomposition of figures by a set of preattentive analyzers. If evidence of perceptual analysis of shapes was found in populations who, like unschooled adults, fail to detect certain sets of segments within a figure, one would be provided with a compelling demonstration of the necessity to distinguish between perceptual and postperceptual processes in visual cognition.

Acknowledgements. This research was partially supported by the Belgian Fonds de la Recherche Fondamentale Collective (FRFC) under Grants 2.4505.80 and 2.4562.86. The first and third authors hold Research Assistant grants from the Fonds National de la Recherche Scientifique (FNRS). Thanks are due to the Editor and two anonymous referees for their help in improving this report.

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