Subtypes of Children with Attention Disabilities*

E.F.J.M. Brand, E.A. Das-Smaal and P.F. de Jong
rije Universiteit, Vakgroep Psychonomie, Amsterdam, The Netherlands

ABSTRACT

Subtypes of children with attentional problems were investigated using cluster analysis. Subjects were 9-year-old-elementary school children ($N = 443$). The test battery administered to these children comprised a comprehensive set of common attention tests, covering different aspects of attentional functioning, and a test of reading comprehension. Cluster analysis of these data yielded eight stable and reproducible clusters. The test profiles of two subgroups were indicative of distinct attentional problems. One group appeared deficient in speed of processing, the other in attentional control. A third subgroup showed a reading deficit. Two additional clusters had very poor and excellent performance on the whole battery, respectively. Finally, three clusters were found with minor variations approximating average performance. The internal validity, that is, the adequacy and stability of the cluster solution, appeared to be reasonably good, as indicated by a variety of measures. The long-term stability over an 18-month period was also checked and found to be satisfactory.

The present article concerns a search for subtypes of attentional disabilities among elementary school children. Considering the various aspects of attention that usually are distinguished in the literature on a theoretical basis, it seems that attention represents a multidimensional concept (e.g., Kinchla, 1980; Moray, 1969; Posner & Petersen, 1990). Empirically, it has been demonstrated that in a set of well known neuropsychological attention tests different attentional factors can be distinguished (de Jong & Das-Smaal, 1993; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991; Schmidt, Trueblood, & Merwin, 1994; Shum, McFarland, & Bain, 1990). Also, a link between different attentional factors and brain structures has been shown (Mirsky et al., 1991; Posner & Petersen, 1990). Therefore, it is conceivable that school children with attentional problems may encounter difficulties in distinct aspects of attention. The aim of the present article is to identify sub-groups with specific (attentional) deficits among children who took part in a recent national survey investigation in the Netherlands (de Jong, 1991).

During the last two decades, research efforts have been invested in subdividing disabled groups of children because of the supposed heterogeneity within these groups. Discrimination of subgroups in broad types of classification syndromes such as hyperactivity, attentional, reading, or learning disorder, which cover heterogeneous groups, is of considerable practical importance because different patterns of abilities and deficits may map onto different etiological factors and prognostic views. This, in turn, may call for quite dissimilar forms of remediation.

Empirical research has made it plausible that distinct types of learning and/or attentional problems indeed do exist (Rourke, 1985, 1991). Subtyping studies have often concerned learn-

ing-disabled children. The usual pattern of subtypes in these studies resembles the results of Lyon (1985), as concluded by Morris (1989) in his commentary of a total of 80 learning-disability subtyping studies. The study of Lyon resulted in five subtypes as follows: visual perception/spatial, phonological syntactic linguistic, sequencing, mixed linguistic/spatial deficit, and general, minor academic problems. Occasionally, a separate subtype with attention deficits was found (see, for example, Hale & Saxe, 1983; Leton, Miyamoto, & Ryckman, 1987; Snow, Cohen, & Holliman, 1985; Snow, Koller, & Roberts, 1987). Some studies on subtypes have included normally developing children as well as learning-disabled children. Here subgroups are found that are labeled as normal, which may not come as a surprise (Bender & Golden, 1990; Hooper & Willis, 1989; Speece & Cooper, 1990).

Subtypes can be found in various ways (Aldenderfer & Blashfield, 1984; Blashfield, 1984). Resulting subdivisions are dependent on the choices that are made early in the classification process regarding the model that is used, the computational technique, and the selection of type of subjects and tasks (Hooper & Willis, 1989).

Regarding the subjects, in contrast to many other studies the present investigation concerned normal elementary school children, without advance selection of particular problem groups. The children were investigated for attentional problems in a survey study by de Jong (1991). The data of this study were cluster analyzed in the present study, because this type of analysis is preferred for a heterogeneous group of subjects. Also, Everitt (1974) notes that in cluster analysis the emphasis of selection is on level and shape. When searching for distinct subtypes of attention deficit, clearly the shape of test profiles is important.

As for the selection of tasks, a broad range of attentional tests was employed in the survey study. These were tests that are commonly used to assess attentional problems in children (de Jong & Das-Smaal, 1993). In addition, reading tests were administered in order to be able to differentiate between attention and reading problems. This was deemed important because attention and reading problems often go together (e.g., Barnes & Forness, 1982; Levine, Bush, & Aufsusen, 1982), and this may easily lead to confusion of symptoms. This, in turn, may hamper a clear diagnosis of the basic aspects of mental dysfunction in both types of deficit (Das-Smaal, Brand, & van den Hooff, 1991; Felton, Wood, Brown, Campbell, & Harter, 1987).

The aim of this study was to identify and examine the internal validity (reliability) of subtypes of attentional problems among elementary school children. A subsequent goal of the enterprise was to determine underlying mechanisms of problems specific for each subtype in an extensive follow-up study. This external validation effort will be described elsewhere and will take place among a selection of children from the current study, that is, children who are most typical to their cluster. In the present study, however, this selection of children will be used to establish the long-term stability of the cluster solution over an 18-month period.

METHOD

Participants

Subjects were 443 Dutch fourth-grade elementary school children, aged 9 years 6 months ($SD = 3.49$ months), who participated in the Dutch National Assessment Study of Attentional Deficit Disorders. An extensive description of the sampling design and the characteristics of the sample is given in de Jong (1991).

In short, a two-stage sampling procedure was used to obtain a representative sample of children in regular Dutch elementary schools who were 9 years of age at a prespecified date. In the first stage, a stratified sample of 111 schools was selected from the population of elementary schools. Two variables were used for stratification: (a) whether the school was situated in an urbanised area (yes or no) and (b) whether the school received extra financial support (yes or no). The latter variable is an indicator of the socio-cultural background of the population of the school. Schools with a high percentage of children from families that belong to ethnic minorities and/or have low socio-economic status receive extra fi-

nancial support. Thus, four strata were made. By design, schools from urbanised areas were slightly overrepresented (see de Jong, 1991).

In the second sampling stage, a maximum of 5 children per school who met the age requirements were randomly selected, resulting in a sample of 552 children. Of these children, 64 were omitted because they had at least one parent who was born outside of the Netherlands. In addition, 45 third-grade children were removed. After removing these children, 443 (208 boys and 235 girls) remained in the sample.

Measures

The task battery employed in the Dutch National Assessment Study (de Jong, 1991) determined the input data for the cluster analysis. The battery comprised, among other measures, a comprehensive set of tests that are, according to test compendia (e.g., Lezak, 1983; Spreen & Strauss, 1991), in common use to assess attentional and reading dysfunctioning in children. A description and justification of the choice of tests can be found in de Jong and Das-Smaal (1993).

Briefly summarized, the set of tests included the following: The *Bourdon-Vos Test* (Vos, 1988), a cancellation test to assess sustained attention; The *Trail Making Test*, from the Halstead-Reitan battery (Reitan & Davison, 1974), to measure speed of visual search and mental flexibility; From the Dutch version of the WISC-R (van Haasen, 1986), *Digit Symbol Substitution* and *Digit Span* forward and backward, both loading on the "Freedom of Distractibility" factor (Kaufman, 1975); The *Verbal Learning Test* (Deelman, 1972), a Dutch version of the Rey Auditory Verbal Learning Test, aimed at verbal learning (mean number of correctly reproduced items on trial two to five) and interference (mean number of correctly reproduced items on the last trial); The *Stroop Color-Word Test* (Hammes, 1978), to measure speed of word reading, speed of color naming, and resistance to interference of a habitual response; The *One Min-*

ute Reading Test (Brus & Voeten, 1979), a test for speed of word reading.

The set of common tests was factor analyzed to aggregate the scores into a smaller set, which served as input for the present study. The structure of the tests was examined by means of a combination of exploratory and confirmatory factor analyses (for details see de Jong & Das-Smaal, 1993). In short, on a random half of the sample an exploratory factor analysis was performed followed by an oblique rotation. Four factors appeared to have an eigenvalue greater than 1. The factors described about 64% of the variance. The factor solution was validated on the other half of the sample using confirmatory factor analysis. The interpretation of the four factors of the final solution appeared to be straightforward (see Table 3 in de Jong & Das-Smaal, 1993). *Factor 1* (see also Table 1), labeled Speed of Naming, represents the three parts of the Stroop Colour-Word Test and the One Minute Reading Test. *Factor 2*, Verbal Learning, is formed by both scores of the Dutch version of the Rey Auditory Verbal Learning Test. The primary indicators of *Factor 3*, Perceptual Speed, are the cancellation task, Digit Symbol Substitution, and both parts of the Trail Making Test. Finally, *Factor 4*, Memory Span, indicates both parts of the Digit Span Test. The structure of the tests appeared to be highly stable across various subpopulations (de Jong & Das-Smaal, 1993).

From the factor analysis it can be seen that standard attention tests are heavily biased towards measurement of speed. The regulatory or control function of attention, which is increasingly emphasized in recent theories of attention (Neumann, 1987; Norman & Shallice, 1986; Navon, 1989a, 1989b), seems to be neglected. However, the National Assessment Study also comprised new tests to measure the control aspect of attention. The data on one of these tests, the **Star Counting Test** (SCT; de Jong & Das-Smaal, 1990), were added in the present study in order to adjust for the speed bias.

Table   Input Variables for the Cluster Analysis.

Variable	Tests
Factor 1 = Speed of naming	Stroop Test, One Minute Reading Test
Factor 2 = Verbal learning	Verbal Learning Test (15 Words Test)
Factor 3 = Perceptual speed	Cancellation test, Digit Symbol Substitution, Trail Making Test
Factor 4 = Memory span	Digit span (WISC-R)
Attentional control	Star Counting Test
Reading Comprehension	Reading Comprehension Test

Note: Variables 1, 2, 3, and 4 concern factor scores.

The Star Counting Test has good psychometric properties and is able to differentiate between attention deficits and various other childhood disorders as rated by teachers (Das-Smaal, de Jong, & Koopmans, 1993; de Jong, 1991; de Jong & Das-Smaal, 1990, 1995). The Star Counting Test assesses attentional control of two simple processes: forward and backward counting. The essential characteristic of the test is the continuing alternation of these processes. Test items consist of a pattern of stars with plus and minus signs in between and a number in the left top corner. Starting numbers vary from 7 to 72. The task is to count the stars by rows from left to right, starting from the initial number, in the direction (forward or backward) indicated by the signs between the stars. The number of the last star is the answer to the item. In the second half of the test, the meaning of the signs is reversed, that is, plus means backward and minus forward counting. Each item is scored correct or incorrect. The complete test consists of 22 items and has a maximum score of 22. In contrast to most of the current attention tests, the SCT assesses accuracy rather than speed.

Regarding reading, the set of common tests represented single-word reading, which appeared to load mainly on a speed factor. In the present study the comprehension aspect of reading was also investigated. The survey data for the **Reading Comprehension Test** (Cito, 1981), a regular Dutch school achievement test, were employed in order to assess reading comprehension. Subjects read five stories with 13 to 33 sentences, each followed by several multiple choice items. The total test contained 25 items. The score on the test was the number correct with a maximum of 25. The input variables are summarized in Table 1.

Procedure

The SCT and the test for Reading Comprehension in the survey study were administered to whole classes. All other tests in the survey study were administered individually. Except for the test for reading comprehension, all testing was performed by trained assistants (see for details de Jong, 1991 or de Jong & Das-Smaal, 1995). The tests for the follow-up study were completed individually and were administered by trained assistants.

RESULTS

Of the 443 subjects in this study, 21 participants did not have a score on the reading comprehension test because they were absent from school at the time of the group administration of this test. These participants were given the mean reading comprehension score.

Outliers can severely distort the results of cluster analysis. Participants were considered as outliers when (a) they had either on one variable a score that differed at least four standard deviations from the mean; or (b) on two variables scores that differed by three standard deviations; or (c) on three variables scores that differed at least two standard deviations from the mean. According to this rule, 29 participants were considered as outliers and were removed from further analysis. As a further check the Mahalanobis distance was computed for each of the remaining 414 participants. Using a chi-square test with an alpha level of .001 (see Tabachnick & Fidell, 1989), no outliers appeared among the remaining participants.

Cluster Analysis

An appropriate cluster solution was obtained in two steps (Everitt, 1974). First, an average linkage hierarchical method was applied, using the program SPSS (Between-cluster Average Distance), to determine the number of clusters and to provide an initial solution for the second step. Because we expected about 4 to 8 clusters, we decided to examine solutions of 2 to 16 clusters. The decision about the appropriate number of clusters was based partly on the internal validity of the solution and partly on its clinical interpretability. Next, Anderberg's k-means clustering method was used (Anderberg, 1973). This k-means procedure starts with an initial solution and then iteratively reassigns individuals to clusters until the profiles remain stable. The stopping rule in the k-means iterative cluster analysis was to stop when not one single case changed from group and when the computed output matrix was identical to the input matrix, that is, the starting values of the k-means clustering. The maximum number of iterations was set to 100, and the average number of iterations was below 10.

Before the cluster analyses were conducted, z-scores were computed for all variables that were entered in the analyses. The squared Euclidean distance measure was used as an index

of similarity, because this measure is often advised in combination with the k-means method (Lorr, 1983). However, because no single similarity index appears to be superior, other measures were also employed.

The internal validity of the cluster solution was evaluated by examination of its stability and with various evaluation statistics. The stability of the cluster solution was determined by (a) split-sample replications; (b) replication with different orders of entrance of the individuals in the analyses; and (c) replication with different initial solutions. For the split-sample replications, the sample was randomly split and the entire cluster procedure was applied to both samples. The split-sample procedure was repeated four times.

For the k-means cluster method, the order in which individuals are assigned to clusters might influence the final solution. The stability of the cluster solution was further tested by entering the individuals in forward and backward order. In addition, for each order, two initial solutions were provided. One initial solution was the exact outcome of the hierarchical cluster analysis. The other solution was derived from the exact solution by restricting all profile scores that were lower than .25 to be equal to zero. The stability of the cluster solution under the various conditions was determined by visual inspection of the cluster profiles.

Several statistics were used to determine the internal validity of the cluster solution. One statistic was GAMMA (Huizinga, 1977; Milligan, 1981), which is based on the notion of compact and well-separated clusters. GAMMA indicates the degree to which an obtained set of clusters approximates a set in which all pairs of cases in the same cluster are more similar than are any two cases in different clusters. In this statistic, both internal cohesion (compactness) and external isolation of the clusters (separation) are comprised. In addition, two statistics were used that indicate either the compactness of clusters (GAMMA-W), or the good separation between clusters (GAMMA-B).

Each of these GAMMA statistics can take on values ranging from -1 to $+1$. A value of $+1$

indicates that all pairs of cases meet the specified criterion, while a value of -1 occurs when no pairs satisfy the criterion. Because the distribution of the GAMMA statistics (GAMMA, GAMMA-W & GAMMA-B) is unknown, it is not possible to determine whether an observed value of a statistic deviates from a value that would be obtained in a set of random data. Therefore, each observed GAMMA statistic was compared to the mean, the maximum, and the minimum of the distribution of the same statistic obtained after the analysis of 100 random data sets. These data sets had the same number of cases as the actual data and were generated from a multivariate normal distribution with a covariance matrix and means that were identical to those of the actual data.

Finally, two additional statistics, the intercentroid distance and the cosine of the angle between cluster centers, were used merely for descriptive purposes. The intercentroid distance is the distance between the centers of the clusters. The cosine of the angle between cluster centers is a measure for the similarity of the mean cluster profiles to a larger angle indicating less similarity.

Next, a hierarchical cluster analysis was performed. Examination of the 2 to 16 cluster solutions indicated that a solution with 16 clusters was the most feasible. Eight of these clusters consisted of a substantial number of cases and were readily interpretable. The other 8 clusters contained a negligible number of cases. Following Blashfield (1984), these 22 cases were considered as outliers and were not included in further analyses. The profiles of the 8 remaining clusters were computed and used as the initial solution for the k-means cluster procedure.

The z-score profiles of the clusters that emerged from the k-means cluster procedure are presented in Figure 1. The characterization of the clusters is straightforward. Two clusters can be denoted as extreme. One cluster had mean scores on the variables that were uniformly low (LOW cluster), while the mean scores of the other extreme cluster were uniformly high (HIGH cluster). Furthermore, three clusters can be regarded as normal (NORMAL1, NOR-
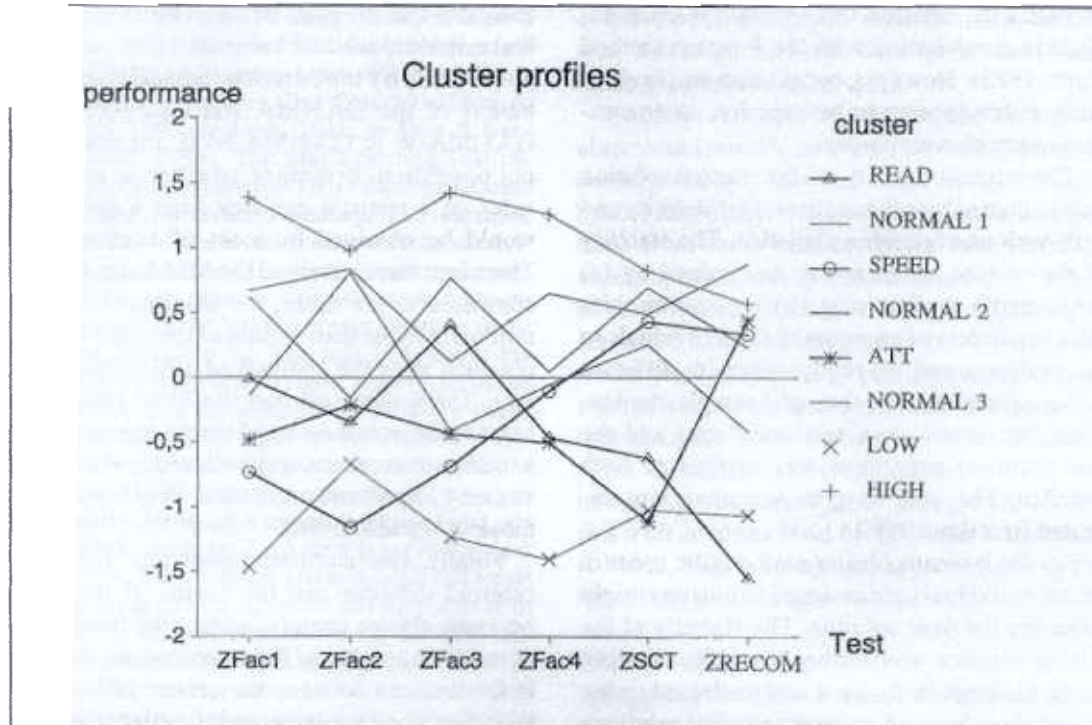
Fig. Profiles of the 8 clusters. (ZFac1 = z-score Speed of Naming; Zfac2 = z-score Verbal Learning; Zfac3 = z-score Perceptual Speed; Zfac4 = z-score Memory span; ZSCT = z-score Attentional Control; ZRecom = z-score Reading Comprehension.)

MAL2, NORMAL3). The mean scores of these clusters were about average and their profiles showed only small variations.

Finally, three clusters had mean scores that varied markedly across the variables. One cluster, the READ cluster, had a particularly low mean score on the reading comprehension test. A second cluster, the attention cluster (ATT), had a low mean score on the SCT and about average mean scores on the other variables. Finally, a third cluster was denoted as a SPEED cluster, because it had below average mean scores on the variables that require speed, that is, speed of naming, speed of verbal learning, and speed of visual processing.

Several methods were used to examine the internal validity (reliability) of the cluster solution. First, the stability of the eight-cluster solution was evaluated by various forms of replication. Analyses of randomly split samples re-

vealed the same number of clusters with similar profiles as in the total sample. When the initial cluster profiles and the entrance order of the cases for the k-means cluster procedure were varied, the normal clusters (NORMAL1, NORMAL2, and NORMAL3) could only be separated in approximately half of the solutions. The other clusters, however, turned up in all analyses.

Next, the GAMMA statistics for the present data and for simulated data were computed. The results are presented in Table 2. GAMMA, the overall index of the compactness and separateness of the clusters, and GAMMA-B, which measures the separateness of clusters only, were satisfactory. The variation between the cases in the clusters was, however, quite large as can be seen from GAMMA-W. Thus, the clusters that were obtained, were discriminated well, but the cases within a cluster were not very similar to

Table 2. GAMMA: Internal Cohesion and External Isolation of Clusters, Overall Estimate of Goodness of Fit

	Internal cohesion within groups GAMMA-W	External isolation between groups GAMMA-B	Overall estimate goodness of fit GAMMA
A: cluster solution after forward sorting $n = 392$	−0.99	−0.78	0.81
B: cluster solution stable cases forward & backward $n = 212$	−0.99	−0.57	−0.6
Mean GAMMA-scores for 100 data sets of simulated data (*SD*)	−1.00 (.00)	−0.92 (.03)	−0.93 (.03)

the most prototypical member of the cluster. Comparison of the GAMMA-statistics obtained with those in the simulated data indicated that it is very unlikely that the clusters in the present study were formed by chance. The observed values of GAMMA and GAMMA-B were smaller than the minimal value that was obtained in the simulated data.

Table 3. Distance Between Clusters in Euclidian Distance and Expressed in Cosine Similarity.

Distances between Final Cluster centres

Cluster	1 READ	2 N1	3 SPEED	4 MIN	5 N2	6 ATT	7 MAX	8 N3
2	2.0616							
3	2.6830	2.2154						
4	2.4898	2.9200	2.6176					
5	3.2125	1.7764	2.7341	4.3554				
6	2.2744	1.9933	1.8913	2.2170	2.6120			
7	3.7811	2.9550	3.9472	5.5766	1.6735	3.9011		
8	2.3977	1.8768	2.2490	3.9198	1.4920	2.5012	1.9770	

Cosine Similarity Coefficient Matrix

Cluster	1 READ	2 N1	3 SPEED	4 MIN	5 N2	6 ATT	7 MAX	8 N3
2	.0355							
3	−.2079	−.3403						
4	.5146	.1395	.4355					
5	−.7557	.1567	−.4206	−.8730				
6	.0514	−.2428	.2582	.6535	−.4402			
7	−.3523	−.0269	−.6065	−.9731	.8263	−.6953		
8	−.2023	−.3481	−.2110	−.7776	.4775	−.7075	.7546	

Finally, the internal validity was determined by the computation of the intercentroid distances and the cosines of the angles between cluster centers. The results are displayed in Table 3. The smallest intercentroid distances were between the NORMAL cluster centres (NORMAL1, NORMAL2, and NORMAL3). The overall level of performance of these three groups was almost the same, but their profiles were slightly different. The largest distances were found between the two extreme clusters (LOW and HIGH). Intermediate intercentroid distances were found among the READ, the SPEED, and the ATT cluster. A consideration of the cosines of the angles between cluster centers revealed that the cosine of the angle between the LOW and HIGH clusters was nearly −1, indicating that these clusters form opposite sides of a single dimension. The cosines of the angles between the specific clusters READ, SPEED, and ATT, however, were approximately zero, indicating that the angle was approximately 90 degrees. Thus, these clusters can be clearly separated and do not form the opposite sides of a single dimension.

Long-Term Stability of the Clusters

After 18 months, a follow-up study was done. The children for this follow-up study were selected from the ATT cluster, the SPEED cluster, the READ-cluster and the three NORMAL clusters, which were joined. From each cluster, a subgroup of 30 children was chosen with the smallest euclidian distance to the cluster centre. For the NORMAL cluster, the centre was defined as the point at which all test scores were average. Of the 120 children who were selected (30 per cluster), 6 children were absent at the time of the retesting and 2 children had incomplete data. Thus, to examine the stability of the clusters, 30 children from the ATT cluster, 25 children from the SPEED cluster, 29 children from the READ cluster, and 28 children from the NORMAL cluster were studied.

Among other tests, which are not relevant for the present study, a number of core tests was readministered in order to examine the stability of the cluster solution. The core tests were assumed to reflect the core features of the READ,

SPEED, and ATT clusters. Thus, the SCT was selected for the ATT cluster, the Bourdon-Vos and the One Minute Reading Test (reflecting processing speed) were selected for the SPEED cluster, and the test for Reading Comprehension represented the READ cluster.

The z-score profiles on the core tests of the four clusters on the first test administration and after 18 months are displayed in Figure 2. The profiles of the clusters appeared to be stable over a period of 18 months, although the differences between the clusters tended to become less pronounced.

A Group (4) × Test (3) multivariate analysis of variance (MANOVA) followed by planned contrasts was performed to examine the differences between the clusters in the follow-up study. The hypothesis was that the shape of the profiles would differ among the groups, that is, that the differences among the groups would vary over the three tests. Thus, we expected a Group × Test interaction effect. Indeed, the MANOVA revealed a significant Group × Test interaction, $F(6, 216) = 6.31, p < .001$, indicating that the shapes of profiles of the four clusters were different.

Planned contrasts were carried out to compare each problem group (ATT, SPEED, and READ) with the NORMAL group. The alpha level of these contrasts was $.05/3 = .013$. Given this alpha level, the shape of the profiles between the ATT and the NORMAL group appeared to differ significantly, $F(2, 107) = 5.28$, $p < .01$. The difference between the shape of the profiles of the READ and the NORMAL group was, given the adapted alpha level, not significant, $F(2, 107) = 3.64, p = .03$, although a clear trend was evident. The profiles of the NORMAL and the SPEED group did not differ, $F(2,107) = .32, p = .73$.

Because the profiles of the SPEED and the NORMAL group were very similar (see Figure 2), we conducted another MANOVA in which the READ and the ATT group were contrasted with the combined NORMAL and SPEED group, the NORMAL/SPEED group. In this analysis, significant differences were found between the shape of the profiles of the READ group and the NORMAL/SPEED group, $F(2,$
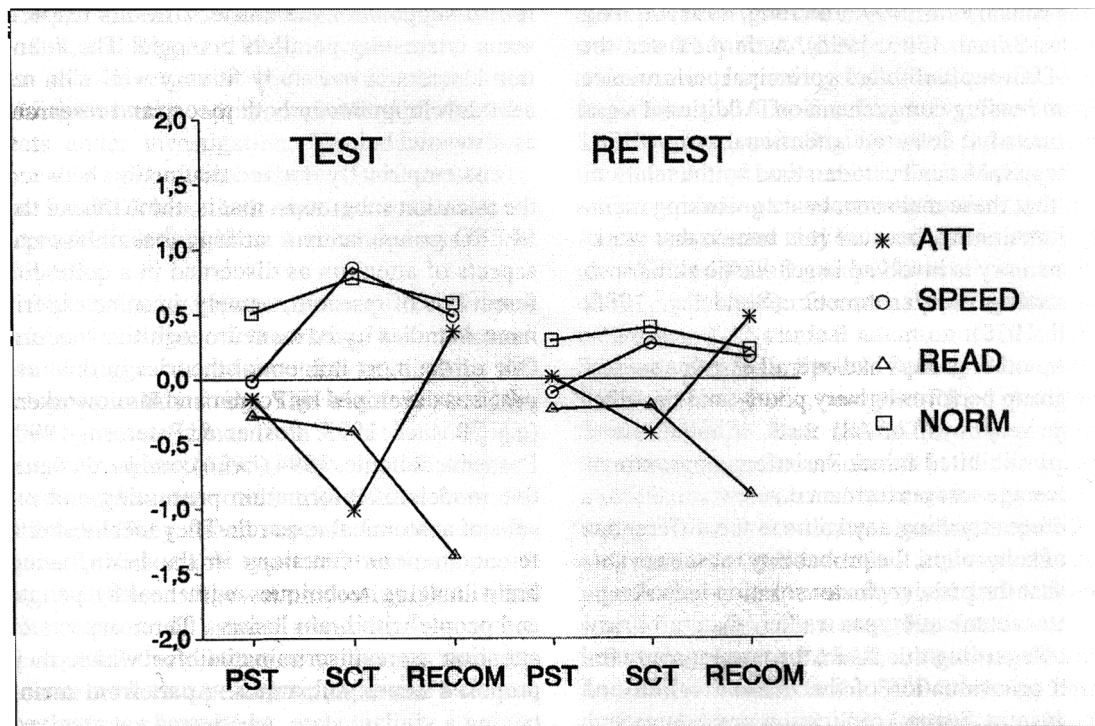
Fig. 2. Test-retest cluster profiles on the core tests. (PST= Perceptual Speed Tests Factor; SCT = Star Counting Test; RECOM = Reading Comprehension. Group means of the original scores (1) as well as the retest scores (2) are given. PST(1) is an aggregated score for factor1, factor2, and factor3 and PST(2) is an aggregated score of the Bourdon Test, the TMT, and the OMT.)

107) = 6.23, $p < .01$, and between the ATT and the NORMAL/SPEED group, $F (2, 107) = 6.92$, $p < .01$. Thus, the MANOVAs indicated that, over a period of 18 months, the READ and the ATT cluster remained distinct clusters whereas the SPEED cluster could no longer be separated from the NORMAL cluster. The shape of the profiles (see Figure 2) revealed that, after 18 months, the READ cluster still had, as expected, a particularly low mean score on Reading Comprehension, and the ATT cluster still had a low mean score on the SCT.

DISCUSSION

The main goal of the present study was to explore whether different subtypes of attention impairment could be found in normal children.

The results indicated two separate aspects in the assessment of attention performance, that is, an attention control and a speed aspect. This difference emerged within the range of the normal school population, with children who generally are not thought to be learning disabled.

Subtyping was done by means of cluster analysis. The analyses suggested the presence of eight stable and meaningful clusters. The profiles of three of the clusters indicated problems in either attention or reading. The SPEED group showed a low level of performance on tasks that were represented by factors labeled speed of naming, verbal learning, and perceptual speed. Impairment seemed to involve speed of (perceptual) processing. The ATT group was characterized by a specific lower performance level on the Star Counting Task, which is a reliable and valid indicator of the control aspect of attention

(Das-Smaal et al., 1993; de Jong, 1991; de Jong & Das-Smaal, 1990, 1995). A third cluster, the READ Group, exhibited a principal performance dip on reading comprehension. Additional signs of somewhat lowered attentional control and memory span can be understood by the relationship that these measures bear to working memory functioning, because it is known that working memory is involved in scholastic skills such as reading and arithmetic (Baddeley, 1986; Hitch, 1978).

Two other groups had overall extreme scores, one group performing very poorly and the other group very well on all tests. Another three groups exhibited minor variations approximating average test performance.

Before attaching any value to the differentiation of subgroups, the probability must be evaluated that the present cluster solution indeed represents actual subtypes rather than arbitrary ones. Regarding this issue, the current study focused on evaluation of the internal validity of the clusters. Several replication procedures and a variety of statistics indicated that the internal validity was good, especially for the three problem groups and both extreme groups. The long-term stability over an 18-month period for selected subgroups was satisfactory. Another concern in this respect is whether the final cluster solution represents shared method variance rather than psychological meaningful dimensions. However, if the solution were the result of a grouping by shared method variance, it would be unlikely that one cluster could be discriminated by both the Verbal Learning factor and the Speed factor, because the tests that indicate these factors consist of very different procedures. In addition, one would predict that in such a solution the ATT group and the READ group would cluster together, because the SCT and the test for reading comprehension employ similar procedures. Therefore, it is more likely that the cluster solution represents meaningful cognitive dimensions.

In cluster analysis, clusters may be internally valid (reliable), but this does not guarantee any meaning (external validity). The question of meaningfulness of a cluster solution pertains to correspondence with other studies and to theo-

retical support for the clusters. In this respect, some interesting parallels emerged. The attention clusters in our study fit very well with recent developments in both theory and research, as discussed below.

The empirically derived distinction between the attention subgroups, that is, the ATT and the SPEED group, bears a striking resemblance to aspects of attention as discerned in a quite different line of research, namely, in some experimental studies based on neurocognitive models. One of the most influential theories in this respect was developed by Posner and his coworkers (e.g., Posner, 1995; Posner & Petersen, 1990; Posner & Raichle, 1994), who combined cognitive models of information processing and results of anatomical research. They localized different attention functions in the brain, using brain imaging techniques with healthy people and people with brain lesions. Three aspects of attention were discriminated, for which they proposed neural substrates. Apart from maintaining a vigilant state, which was not assessed in our study, they discerned visual orienting and executive control. Posner and Raichle (1994, p.177) concluded that "operations performed by the executive network are quite different from those performed by the visual orienting network", where the executive attention network exercises some form of control over the visual orienting function.

Based on the work of Pribram and McGuinness (1975), Tucker and Williamson (1984) proposed a comparable distinction, that is, between a perceptual input selection mechanism facilitated by arousal, and a mechanism for the internal control of action, related to activation. They presented evidence regarding the neurotransmitter substrates of these systems and their localization in the brain.

Thus, in line with our ATT and SPEED group difference, both approaches assume a regulatory or attention control mechanism that is cognitively distinct and neuroanatomically separate from an attention mechanism for perceptual input. The neuroanatomical mappings, however, are dichotomized frontal-parietal by Posner (Posner & Petersen, 1990; Posner & Richle, 1994), and left-right by Tucker and Williamson

(1984). Recently, Goldberg, Harner, Lovell, Podell, and Riggio (1994) were able to account for this divergence by showing that both descriptions may apply, depending on the subjects under investigation. They demonstrated that although both attention mechanisms involve the frontal lobes, their exact neuroanatomy is dependent on the gender and handedness of the subjects.

The similarity between our empirical distinction and the line of theorizing just indicated would suggest some external validity for the subtypes in this study. This claim is strengthened by new evidence from Johnston, McCann, and Remington (1995), who applied chronometric techniques to identify distinct forms of attention. They found support for two experimentally dissociable types of attention, operating at different stages of processing, that is, input attention and central attention. Johnston et al. equated this distinction to the one made by Posner between a perceptual input and a control mechanism of attention.

Factor analytic studies on attention are also relevant to our results. These studies equally bolster an ATT and SPEED group distinction. Mirsky et al. (1991) presented a model including four attentional elements that was empirically supported by their demonstration of four different factors in a set of well-known neuropsychological attention tests. These included perceptual speed, flexibility, vigilance and numerical-mnemonic. Except for a vigilance task and an arithmetic test, input data for the present study concerned the same or comparable tests as were used by Mirsky et al. In terms of their model, our cluster analysis yielded a specific flexibility group (ATT) and a speed group (SPEED). A numerical-mnemonic group did not emerge, probably because our study did not include an arithmetic test.

In an attempt to examine the construct validity of eight commonly used clinical attention tests, Shum, McFarland, and Bain (1990) identified three stable factors in samples of normal and head-injured subjects. These were labeled visuo-motor scanning, sustained selective processing, and visual/auditory spanning. Schmidt, Trueblood, and Merwin (1994) conducted a par-

tial replication of this study, omitting serial subtraction. They found comparable results in that a visuo-motor scanning factor and a weak span factor emerged. The first factor is related to the SPEED group, with Digit Symbol Substitution, the cancellation task, and the Trail Making Test as corresponding characteristic tests.

The span factor may be more associated with our ATT and READ group. However, in a methodologically stricter factor analysis on a broader collection of 12 clinical attention tests, adding Seashore Rhythm, Speech Sounds Perception, WAIS-R Arithmetic, and the Paced Auditory Serial Addition Task (PASAT), only a single factor emerged. Here, Schmidt et al. eliminated multiple measures from the same test by selecting scores with the highest loading in preliminary factor analyses. As they indicate, this approach may not neccessarily yield the best measure of attention for a test. Nevertheless, it is interesting that the PASAT, a measure of attention control similar to the SCT (de Jong, 1991; de Jong & Das-Smaal 1995), appeared to be the better test of attention. The PASAT was the one most likely to classify outpatients referred for neuropsychological evaluation as impaired.

Finally, other cluster analytic studies should be considered in relation to our results. As stated earlier, subtyping studies have been done before, but not with the objective of the present study. Our aim was to identify subtypes among normal school children, as discernible in psychometric attention test data generally obtained for referred children. Most other studies have used children with learning disabilities and tests of varying nature. The difference in objectives makes a straightforward comparison somewhat problematic, because cluster results are dependent on the type of subjects and tests employed. Nonetheless, it may be interesting to see how the current results relate to these studies.

In cluster analytic studies, it is not unusual for three to six subtypes to emerge. Morris (1989) described five subtypes as follows: visuo-spatial, linguistic, mixed linguistic-spatial, sequencing, and aspecific deficit subgroup. The present SPEED group seems to coincide with the visuo-spatial group, whereas the READ group resembles most closely the linguistic sub-

group. The idea that these groups are similar is rather speculative, however. The ATT group has no characteristics of any of the current groups from Morris' summary. This can be understood if one realizes that the control aspect of attention, as outlined in the introduction, is not usually tested in other studies. A comparison with the overviews from Hooper and Willis (1989) reveals that both the SPEED and the READ subtype are not uncommon. In addition, in their overview, Hooper and Willis mention an attention subtype twice. From their report it cannot be determined whether or not these subtypes concern the control aspect of attention, as our ATT subtype does.

In conclusion, the present investigation identified two subtypes of attentional problems among elementary school children, and these were distinguishable from a subtype with problems on reading comprehension. The profiles of the attention subgroups indicated impairments on either a control or a (perceptual) speed aspect of attention. These empirically derived subtypes received some validation support from the results of quite different lines of research on attention.

The internal validity and the long-term stability of the cluster solution appears to be reasonably good. The apparent tendency of diminishing differences between cluster profiles over a period of 18 months can be explained by the principle of regression towards the mean. Over this relatively long period, the profiles of the SPEED and the NORMAL group became similar, but the ATT and the READ groups still appeared to be distinct clusters. Nevertheless, the external validity of the cluster solution should be researched further. This is the aim of a follow-up study, in which the underlying mechanisms of attention problems will be examined by testing a wide variety of more basic cognitive abilities.

In light of the pervasiveness of attention disturbances among school children, and the generally negative effects on academic performance, further attempts at refining assessment of attention are an urgent matter. As a result, we may be able to develop specific treatment programmes for the benefit of all types of children.

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