

Hierarchical Agglomerative Cluster Analysis as a Trial Method Revealing Developmental Coordination Disorder (DCD) Subtypes

Katerina Asonitou^{1*}, Gerasimos Prodromitis² and Dimitra Koutsouki¹

¹Laboratory of Adapted Physical Activity, Developmental and Physical Disabilities, School of Physical Education and Sport Science, National and Kapodistrian University of Athens, Greece

²Department of Psychology, Panteion University of Social and Political Sciences, Athens, Greece

*Corresponding author: Katerina Asonitou, Laboratory of Adapted Physical Activity, Developmental and Physical Disabilities, School of Physical Education and Sport Science, National and Kapodistrian University of Athens, Greece, Tel: +302107276021; Fax: +302107276032; E-mail: kasonitou@phed.uoa.gr

Received date: July 08, 2017; Accepted date: August 05, 2017; Published date: August 08, 2017

Copyright: © 2017 Asonitou K, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Abstract

Background: There is increasing evidence that children with DCD have been classified into distinguishable 'subtypes' mainly based on perceptual-motor, fine and gross motor skills. Previous research efforts define and describe in detail subgroups of DCD using the methods of cluster analysis. The hierarchical agglomerative cluster analysis seems to be an effective statistical method to identify homogeneous subtypes in the developmental disorder literature.

Methods: The present study investigated the nature of possible cognitive-motor profiles of DCD using clustering methods. Dependent variables were selected on the basis of the characteristics of children with DCD and the specific difficulties observed in cognitive- motor domain according to the DCD literature. For the purpose of the study we adopted "PASS" neurocognitive theory (Planning, Attention, Simultaneous, Successive) and the norm-referenced Cognitive Assessment System.

Results: Based on this hierarchical agglomerative cluster analysis six (6) statistical sub-groups emerged with number of participants ranged from 5-43 students with or without DCD. Internal and external validity of the clustering solution was controlled by different clustering methods (Wards method analysis, Complete Linkage method, Centroid method, K-Means iterative partitioning method and split-sample replication), as well as other parametric methods (MANOVA, ANOVA and discriminant analyses).

Conclusions: Future research examining the impact of DCD classification is warranted and it could be apply for other developmental disorders. The impact of different DCD profiles may provide larger benefits for alternative and effective instructional methods and early intervention programs in order to avoid motor learning disabilities and low academic achievement.

Keywords: DCD subtypes; Motor skills; Cognitive processes; Hierarchical agglomerative cluster analysis

Abbreviations: MD: Manual Dexterity; SB: Static Balance; DB: Dynamic Balance; RUN: Running; PL: Planning; SC: Simultaneous Coding; ATT: Attention.

Introduction

Different methodological and statistical approaches have been followed to classify children with DCD and identify subgroups. Children with DCD have been classified into distinguishable 'subtypes' mainly based on perceptual-motor, fine and gross motor skills [1-5] (Dewey & Kaplan 1994; Green, Champsers & Sugden 2008; Hoare 1994; Macnab et al. 2001; Wright & Sugden 1996b). These detailed studies describe in detail subgroups of DCD using the methods of cluster analysis.

Used a hierarchical agglomerative cluster analysis [1], followed by a K-means iterative approach, to identify distinct subtypes of motor planning. Participants were 102 children (6-12 years old) from the public schools; 51 were identified as having a developmental motor

deficit and 51 were age and sex matched controls. The variables entered into clustering solution identified their abilities in motor planning and motor execution. The research design included measures of balance, transitive gesture, and motor sequencing which were compared together with assessments of academic, language, visual-perceptual, and visual-motor skills. Standardized residual scores were used to control for the effect of age. The residual scores were standardized relative to the total sample mean. Therefore, profile descriptions represent performance relative to average performance of the control and motor deficit groups combined. The authors identified four (4) clusters (subgroups). Cluster 1 (n=12): severe deficits in all areas. Cluster 2 (n=21): deficits in balance, coordination, and transitive gestural performance. Cluster 3 (n=7): deficits in motor sequencing tasks. Cluster 4 (n=62): no motor deficit.

The second and third sub-group had the greatest importance according to [4]. In the second subgroup were noted difficulties relative to the execution of motion (performance of the motor action), while the planning remained intact; difficulties in the third subgroup were relative to planning processes.

The no motor deficit cluster included the most children from the control group (49 out of 51) and 12 children from the motor deficit group. These 12 children suggested that either they were wrongly diagnosed or their difficulties were minimal. The conclusion of the findings was that DCD could be conceptualized as either a planning disorder, strongly associated with the theoretical background of MABC in assessment and intervention (problems in knowing what to do and how to move) or execution disorder with planning remaining intact (poorly coordinated performance in children who know what to do) [6].

Green, Champers & Sugden [2] used similar statistical procedures to those of Hoare and Macnab et al. [3,4] for their subtyping study. The combined group of children with and without co-morbidity (N=90) showed five (5) clusters: cluster 1. (n=34) relative strength across perceptual-motor items; cluster 2. (n=13) relative strength in perceptual functions and fine-motor skills; cluster 3. (n=10) poor static and dynamic balance; cluster 4. (n=22) poor perceptual and fine-motor tasks. Greater problems were found in visual-spatial, kinesthesia, and manual dexterity items, with a relative strength in balance items; cluster 5. (n=11) poor performance across all items.

Hoare [3] identified five patterns of perceptuo-motor dysfunction among 80 children with DCD 6-9 years old that were evaluated in a "battery" of 32 perceptual and motor tests. The kinesthetic acuity, visual perception, visual-motor integration, manual dexterity (Purdue Pegboard), static balance and run were the variables included in hierarchical agglomerative cluster analysis. Five (5) perceptuo-motor dysfunction subtypes were obtained: cluster 1. (n=22) poor dynamic balance and kinaesthetic acuity; cluster 2. (n=20) visual-perceptual competencies with poor kinaesthetic acuity; cluster 3. (n=15) visual-motor deficits ("generalized perceptual dysfunction" with most problems in perceptual & fine motor tasks); cluster 4. (n=14) poor static balance and visual perceptual/visual-motor functions, and cluster 5. (n= 8) poor static and dynamic balance (gross-motor dysfunction). It is essential finding that the 67% of cluster 3 (10 from 15 DCD children) also faced learning disabilities. The presence of difficulties in specific developmental domains makes one group different from another, although belongs to the same population (DCD). Therefore, it is not legitimate to give the title of the "syndrome" for a child experienced movement difficulties, generalizing the problems of a single subgroup [3,7]. Hoare demonstrated the heterogeneity of the population and recommended the classification of the disorder as an effective tool for appropriate intervention.

Macnab et al. [4] examined in detail three studies [1,3,8], which used the hierarchical agglomerative cluster analysis. The aim of the study was to examine the use of cluster analysis as a method of exploration subgroups of DCD to better understand how different samples and different measures affect the interpretation of results. Using a similar protocol to Hoare's [3] study with different clinical sample, Macnab et al. [4] tried to identify possible reasons for different results. They found similar groupings to Hoare [3].

The subtyping study of Wright and Sugden [9] considered the interaction of the environment on the motor capabilities of children with DCD. These researchers found some evidence for a separation of fine-motor skills versus gross-motor skills requiring responses to environmental changes. The results was consistent with Piek et al. [10] study suggesting a differentiation of ability by problems of fine-motor, gross-motor and complex motor skills.

According to Macnab et al. [4], the most important finding was that the profile of subgroups is maintained. A similar subtype with good (static) balance was found in different studies [1,3,4,8]. The balance was one of the few variables measured consistently across all relevant studies. Also, despite the differences in these four research trials [1-5] a common subgroup highlighted, which characterized by generalized problems in all examining domains. In Hoare [3] this subgroup was characterized by "generalized perceptual-motor dysfunction". The remaining subgroups had difficulties in specific domains (catching, manual dexterity, balance, etc.).

All previous studies used a hierarchical agglomerative cluster analysis followed by K-means iterative partitioning method to identify homogeneous subtypes in the DCD literature. The variation in results may be attributable to different samples, measures or statistical methods, affecting on the interpretation of the clusters structure. A similar subgroup with poor balance, as well as a common with difficulties in all areas of perceptual-motor skills (including fine, gross, visual-spatial and complex) were found in all above studies. Also, the severity of motor performance deficits were associated with the degree of visual-motor impairment in clusters 3 and 4 across Hoare's [3] and Macnab et al. [4] studies.

Goals of the Present Research

The present study investigated the nature of possible cognitive-motor profiles of DCD using clustering methods. Dependent variables were selected on the basis of the characteristics of children with DCD and the specific difficulties observed in cognitive- motor domain according to the DCD literature.

For the purpose of the study we adopted "PASS" neurocognitive theory (Planning, Attention, Simultaneous, Successive) [11-13] and the norm-referenced Cognitive Assessment System (CAS) [14]. Subtypes of children with DCD could be identified based on their performances on cognitive subscales of CAS, which was adopted to assess the children's cognitive abilities.

Methods

Participants and selection procedure

Stratified randomization [15] was done according to age band (4-6 years), gender, nationality as well as the region of the kindergartens in the city of Attica (north, south, west, east Attica: a metropolitan region, the most densely populated prefecture in South Greece). Participants included 108 Greek children, 54 with developmental coordination disorder (DCD) and 54 without DCD, 5-and 6-year-old, (36 boys and 18 girls respectively match paired; (mean age: M=66.48 months, SD=4.6). Variables were used for cluster analysis included cognitive functions of planning, simultaneous and attention processing.

All students were enrolled in a regular public kindergarten school and had never diagnosed with any physical impairment or intellectual disability. Those children who scored below the 15th percentile for their age on the MABC were included in the DCD group. The total standard score on the MABC [16] classified students into three categories: a) <10 without DCD (ok), b) 10-14 with moderate difficulties ("at risk"), c) >14 serious problems with motor coordination (DCD-"movement problem"). Thus, the sample of 54 DCD students was characterized by varying degrees of motor dysfunction ("at risk" or "severe"). Specifically, based on this classification the category "10-14 at risk"

included 14 students (N=14) and the category "above 14-severe" included 40 students (N=40). The control group had no symptoms of DCD, as indicated by the children's teachers, as well as their MABC standard scores [16].

All children met the DSM-IV [17] criteria for DCD as they all demonstrated significant or moderate motor deficits on the MABC (Criteria A) [16]. These impacted on their daily lives and/or academic performance, according to parent report (Criteria B). None had other medical or neurological conditions (e.g. significant prematurity, epilepsy, attention deficit hyperactivity disorder, mental disability) (Criteria C). None of the children had identified intellectual difficulties (Criteria D) and were attending regular public kindergartens in the city of Attica.

Instruments

Motor assessment

The Movement Assessment Battery for Children (MABC) [16] was used to assess motor difficulties. Standard scores were obtained from the test manual and used in order to confirm the existence or not of DCD. It is a norm-referenced test which assesses performance in three motor domains: a) manual dexterity, b) ball skills, and c) static and dynamic balance. Reliability and validity of the MABC are good and available in test's manual [16].

The MABC has been used widely in the scientific research for detection and evaluation of children with and without clumsiness [5,18-23]. Further, it has been used in Greek studies [18,24,25]. According to Sugden and Wright [6] the MABC satisfies the requirements of DSM-IV [17], about the definition of the disorder (significant motor impairment and difficulties of a functional nature in everyday life).

The running speed, which is a gross motor ability, were tested with the standardized task "Running speed and Agility" of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) [26], like the research of Macnab et al. [4]. Previous studies have shown that running is a crucial gross motor test for children with DCD [3,4,8]. Hoare [3] found that clumsy children had the greatest difficulties in tasks required gross movement of the body.

Cognitive assessment

The Cognitive Assessment System (CAS) [14] was administered to assess cognitive-executive functions of students. CAS is a norm-referenced test, which identified specific strengths and weaknesses in cognitive processing and predicts academic achievement in children. Three major cognitive domains were used: a) Planning Scale, b) Attention Scale, and c) Simultaneous Coding Scale. The standard scores among the individual Scales have relevance to successes and failures in specific areas of academic performance [12,27]. Reliability and validity of the CAS are good and available in test's manual [27]. The three processes (Planning, Attention, and Simultaneous) were measured using the CAS, an individually administered test for children aged 5 through 17 years designed to measure basic psychological processes [28].

Procedures

Standardization of the sample and cluster analysis

The definition of DCD according to DSM-IV [17] and the cut-off points of MABC [16] were the major criteria in order to analyze the research data including students with severe or borderline motor coordination problems.

Participation of students without DCD in cluster analysis was important [1]. In other similar studies cluster analysis administered exclusively on DCD population [2-5,9]. In our study all participants, with and without DCD (N=108), were included in cluster analysis. So, it was tested if the clustering methods could separate the two groups. This separation is a valid confirmation criterion for the expected results of our study [1]. Furthermore, it is revealed the clumsiness level (level of impairment) of the sample.

According to literature [29-31] must be taken into account the following (4) basic criteria in cluster analysis: a) variables selected should maximize the differences between the subgroups emerged by cluster analysis; b) variables should have a theoretical basis; c) there is no overlap between the variables and the task that measure to be clear; d) the variables have sufficient reliability. Given this theory, basic criteria for selection and inclusion of variables in cluster analysis were the factor analyses results previously applied. Factor analyses were used before clustering methods, in order to reject redundant variables could obscure the cluster analysis and minimize the number of variables. It is very important to include the smallest possible number of variables [29,30,8].

After selection of variables all scores standardized to z range for both age groups (5-and 6-year-old, N=108) with a mean of zero (Mean=0) and a standard deviation of one (SD=1). The non DCD group was needed to create the total population norms of the study. The standardization of variables was needed because cluster analysis is partly dependent on the standard deviations of the variables included in the investigation [32]. Another criterion is the requirement of statistical method K-Means to standardize the data for validation of results (SPSS, 2000).

The standardization of data and the process through cluster analysis method included the following seven steps:

1. In order to standardize the scores by examining the variables we needed norms. Because there were no Greek norms in motor and cognitive level for the general student's population, norms of research sample had to be created (sample norms).

2. According to research data and the international scientific literature the incidence of DCD amounts to 6-10% of school-aged children 5-11 years (DSM-IV, 1994) or 5-6% [33] with typical diagnosis in infancy or entering in primary education. On the other hand, children with and without DCD coexist in classrooms; therefore, we selected all children without DCD (N=54) and added six children with DCD (N=6). This consisted the representative sample (N=60) from which obtained the norms for the total sample (N=108).

3. The third stage was the control of skewness & kurtosis of distribution curve to investigate the variability of variables before standardizing (11 motor and 22 cognitive). Criteria was being the point $\geq \pm 2.00$ for skewness and the point $\geq \pm 5.00$ for kurtosis [34,35]. Four cognitive variables (matching number 3, matching number 4, number detection 3, number detection 4) were excluded from analysis

as well as those of the participants had extreme scores (outliers), greater than ± 3 SD from average [7,35]. It has been found that the extreme scores create distort in clusters [36].

4. In the fourth stage, 60 children were divided into two age categories (5 and 6 years). For each age group the average and SD for each variable consisted the norms for the total sample (N=108). The subgroups profiles that resulted from cluster analysis reflect the performance of children in relation to the norms of the present study's sample (N=108) (not in relation to norms of the general Greek population). However, since the investigation of subgroups was formed within the physical surround of general school population (where coexist both children with and without DCD), the sample was the best representative of the population attending general schools.

5. In the fifth stage, the total sample (N=108) was divided into 5 and 6 years old students. Then, the scores for each variable standardized (in z scores), according to the Mean and SD of 60 children was normative sample. By standardization we:

- a) Isolated statistically the effect of age, and
- b) "equalized" variables as they were measured on different scales [29].

6. In the sixth stage was used factorial analysis to z scores separately for motor and cognitive variables.

7. In the seventh stage cluster analysis was applied to determine subgroups based on their performance scores in motor and cognitive tests [28].

Statistical analyses

Statistical Package for Social Sciences (SPSS) 19.0 software for Windows was used for analysing the data [37] with probability level of $p < 0.05$ statistically significant [38]. Firstly, factor analyses were applied to performance of students with and without DCD (N=108) on 31 cognitive-motor variables on z scores (standardized scores), to isolate possible factors.

The variables were selected according to DCD literature about the characteristics and the difficulties these children face in specific motor and cognitive skills. The purpose of the factorial analysis was to "retrieve" and group together those variables that had a high correlation with each other. Also, factorial analysis contributed to ensuring the minimum number of variables will be used later in cluster analysis [3].

The selection of variables grouped under the motor and cognitive factors, following specific criteria: a) factor loadings over 0.40, b) loadings with the appropriate factor, and c) no double factor loadings, d) factors with eigen values greater than one (1.0) [35]. Finally, we calculated the reliability coefficient Cronbach alpha. Cronbach alpha reliability factors were 0.76 for manual dexterity, 0.79 for dynamic balance and run, and 0.81 for static balance.

Cronbach alpha reliability factors were 0.92 for planning, 0.84 for attention, and 0.66 for simultaneous coding.

Specifically, it was applied separately two factorial analyses; first for 11 motor variables and second for 20 cognitive variables. Motor variables grouped in the following three (3) factors:

1st factor (dynamic balance): dynamic balance 1, dynamic balance 2, running, with eigen value 2.33 and a 21.15% and a 21.15% rate of interpretive dispersion.

2nd factor (manual dexterity): manual dexterity1/dominant hand, manual dexterity 2/non-dominant hand, manual dexterity 2, manual dexterity 3, with eigen value 2.30 and a 20.87% rate of interpretive dispersion.

3rd factor (static balance): static balance/dominant leg, static balance/non-dominant leg, with eigen value 1.70 and a 15.43% rate of interpretive dispersion.

Overall, the percentage of interpreted dispersion by the three factors was 57.45%.

Two variables of ball skills (ball skills 1, ball skills 2) were excluded from cluster analysis, because in factor analysis previously they had dual loadings (double factor loading) (PP1) and high loadings (high factor loading) (PP2) with a wrong factor titled 'dynamic balance & running'.

Cognitive variables were summarized in the following three (3) factors:

1st factor (attention): receptive attention 1, receptive attention 2, receptive attention 3, with eigen value 4.51 and a 25.06% rate of interpretive dispersion.

2nd factor (simultaneous coding): nonverbal matrices, verbal/ spatial relations, with eigen value 3.77 and a 20.92% rate of interpretive dispersion.

3rd factor (planning): planned codes 1, planned codes 2, with eigen value 2.02 and a 11.21% rate of interpretive dispersion.

Overall, the percentage of interpreted dispersion by the three factors was 57.19%.

Thirteen cognitive variables were excluded from the following statistical processes because they were not grouped in any factor describing the cognitive abilities of kindergarten students (matching number 1, matching number 2, planned codes 3, planned codes 4, planned connections, figure memory, expressive attention 1, expressive attention 2, number detection 1, number detection 2, receptive attention 2, receptive attention 4, receptive attention 6). It seemed that above cognitive variables as well as ball skills are not grouped into a factor that describes the preschoolers' cognitive-motor performance and were excluded from subsequent statistical analyses [28].

Variables included in hierarchical agglomerative cluster analysis

The six (6) factors (dynamic balance, manual dexterity, static balance, attention, simultaneous coding and planning) included variables were subjected to a series of cluster analyses. A combined approach by hierarchical agglomerative cluster analysis applied based on students' performance in the standardized z scale scores on nine (9) motor and seven (7) cognitive abilities to identify possible statistical cognitive subtypes in children with and without DCD (N=108). The hypothesis was if the clustering methods could separate the two groups, and show the interaction between children with and without DCD into subgroups based on cognitive and motor abilities.

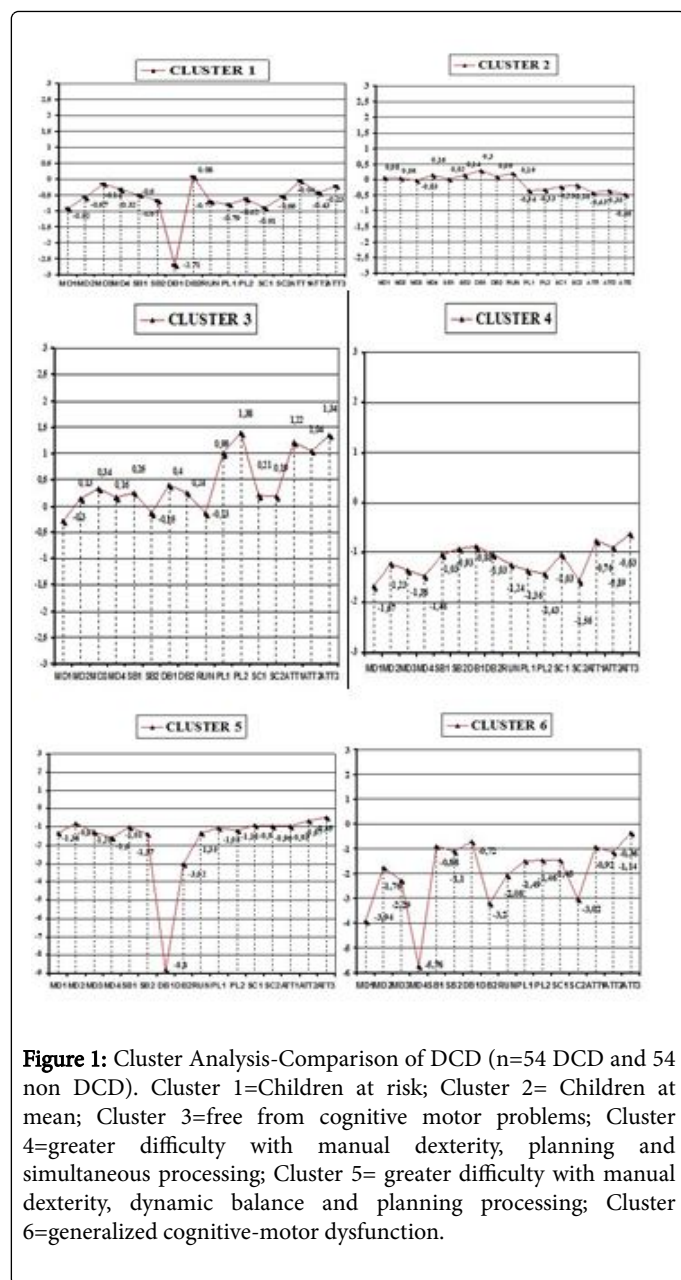


Figure 1: Cluster Analysis-Comparison of DCD (n=54 DCD and 54 non DCD). Cluster 1=Children at risk; Cluster 2= Children at mean; Cluster 3=free from cognitive motor problems; Cluster 4=greater difficulty with manual dexterity, planning and simultaneous processing; Cluster 5= greater difficulty with manual dexterity, dynamic balance and planning processing; Cluster 6=generalized cognitive-motor dysfunction.

Specifically, the variables were the following:

A) Motor skills: manual dexterity 1 (MD 1: posting coins-dominant hand), manual dexterity 2 (MD 2: posting coins-non-dominant hand), manual dexterity 3 (MD 3: threading beads), manual dexterity 4 (MD 4: drawing a line into a trail), static balance 1 (SB 1: one-leg balance-dominant leg), static balance 2 (SB 2: one-leg balance-non dominant leg), dynamic balance 1 (DB 1: jumping over a cord), dynamic balance 2 (DB 2: walking along a line with heels raised), and running speed and agility (DB 3: 13.7 meters).

B) Cognitive Abilities: planned codes 1 (PL 1: number of correct answers), planned codes 2 (PL 2: number of correct answers), nonverbal matrices (SC 1: number of correct answers), verbal/spatial relations (SC 2: number of correct responses), receptive Attention 1 (ATT 1: secs required for pairs of picture matching, visually alike), receptive Attention 2 (ATT 2: secs required for pairs of picture

matching, visually alike), receptive Attention 3 (ATT 3: secs required for pairs of picture name matching-taxonomy to the same category) [28].

Results

Based on this hierarchical agglomerative cluster analysis six (6) statistical sub-groups emerged with number of participants ranged from 5-43 students [28]. Internal validity and external validity of subgroups were examined then (Figure 1):

A group displayed relatively low below average scores on simultaneous processing tasks (children at risk: 5 without DCD and 4 with DCD),

A group (the largest) displayed scores close to the mean on all tasks (children on the mean: 35 without DCD and 8 with DCD),

A group displayed performance above average scores on all tasks (free from cognitive problems: 13 children, all without DCD),

A group displayed greater difficulty with the planning and simultaneous processing tasks (1 without DCD and 25 with DCD),

A group displayed greater difficulty with the planning tasks (12 children, all with DCD),

A group displayed the lowest scores on all tasks (generalized cognitive dysfunction: 5 children, all with DCD).

Internal validity (reliability) of clusters was controlled by replications of the clustering solution with different clustering methods (Wards method analysis, Complete Linkage method, Centroid method, K-Means iterative partitioning method), as well as split-sample replication. External validity refers to the relevance of the classification obtained by cluster analysis and it was controlled by multivariate analyses of variance and discriminant analyses [29]. The results were sufficient and satisfactory.

Ward's, Complete Linkage and Centroid methods were administered and compared with K-Means iterative partitioning method for the control of misclassifications between six clusters.

-Ward's and Centroid methods produced overall recovery of K-Means groups at 100%.

-Complete Linkage method resulted in a lower recovery rate of 72.3%.

Split-sample design was used then. All children (N=108) were randomly assigned in two subsamples. K means analysis showed that no subjects changed from their original cluster in split sample 1 and split sample 2.

External validity results were as following:

A) Separate MANOVA analyses to examine multivariate differences among the six (6) clusters. We expected significant differences ($p < 0.05$).

B) Discriminant Function Analysis to examine the motor and cognitive tests that separates students in six clusters and the percentage of students who were correctly classified.

C) Sixteen one-Way ANOVAs to consider differences between six clusters based on nine (9) motor and seven (7) cognitive variables. The results showed that the six subgroups differed significantly in all of the motor and cognitive tests.

The overall results for the external validity showed:

Significant multivariate differences ($p < .05$) between six subgroups for the nine (9) motor skills (Wilks' Lambda=0.015, $F=14,635$, $p=0.000$, eta squared=0.568). Discriminant analysis then showed that the variables separated the six subgroups were as follows:

Zm9 (dynamic balance-jump with $F=224.54$, $p=0.000$),

Zm4 (manual dexterity-tracking with $F=83.50$, $p=0.000$),

Zm1 (manual dexterity-posting coins with $F=47.77$, $p=0.000$), and

Zm3 (manual dexterity-threading beads with $F=33.89$, $p=0.000$).

The prediction equation for each variable was:

$$Y = -1.587 + 1.150 * X_{zm9}$$

$$Y = -1.587 + 0.085 * X_{zm4}$$

$$Y = -1.587 + 0.066 * X_{zm1}$$

$$Y = -1.587 + 0.199 * X_{zm3}$$

Finally, the correct prediction rate of the above four motor skills was 70.4%.

Significant multivariate differences between six subgroups for the seven (7) cognitive abilities (Wilks' Lambda=0.207, $F=5.263$, $p=0.000$, eta squared=0.270). Discriminant analysis then showed that the variables separated the six (6) subgroups were as follows:

Zc15 (planned codes-1 with $F=22.72$, $p=0.000$),

Zc28 (attention-7 with $F=15.33$, $p=0.000$), and

Zc18 (verbal-spatial relations with $F=11.40$, $p=0.000$).

The prediction equation for each variable was:

$$Y = -0.762 + 0.875 * X_{zc15}$$

$$Y = -0.762 + 0.049 * X_{zc18}$$

$$Y = -0.762 + 0.902 * X_{zc28}$$

Finally, the percentage of correct prediction of the above three cognitive skills was 67.2%.

Discussion and Conclusions

The results confirmed the heterogeneity and various cognitive subtypes of children with DCD. The identification of subtypes helps researchers, educators and clinicians to plan more effective intervention based on children's cognitive-motor difficulties. Based on such methodological clustering approach the occupational could determine the specific domain in which students had difficulties on how to learn new motor and cognitive academic skills or how to execute and perform properly the tasks that require or do not require a motor response. The subgrouping highlights the need for "type-specific remediation" [8].

The specific theoretical model of information processing with both assessment of motor coordination and cognitive difficulties interpreted the identification of subgroups in children with and without DCD as well early detection of learning difficulties. Thus, the application of an internationally reliable cognitive neuropsychological model assists to explain the disorders of coordination as well procedural learning in clumsiness (which includes motor control).

We identified differences in knowledge base [39] existed between children with and without DCD by application a thorough holistic neuro-cognitive theory of information processing (PASS theory) [40,41]. The results of this study showed that, according to the cognitive theoretical PASS model [40,41], in most children with DCD (subtypes 1, 4, 5, and 6) the impairment in cognitive abilities accompanied with movement difficulties. So, whether cognitive tasks (associated with academic courses) or motor tasks, there is a problem in learning ability and performance when display difficulty in processing incoming information through planning, coding and attention.

The difficulty of information processing through these three domains (attention, coding, planning), involved with memory and individual's knowledge base, can lead to motor (DCD) or learning difficulties (LD) or attention hyperactivity disorder (ADHD). For that reason, a cognitive approach with scientific theoretical basis, both in assessment and intervention of these developmental disorders, it is necessary, because it gives detailed information about the strengths and weaknesses of children. In particular, when assessment and intervention have early application of pre-school age, have a crucial role in preventing and improving disorders [25].

Some children seem to grow out of their motor difficulties with or without intervention, while others still appear to have movement disorders in adolescence and adulthood [42-45]. Subtypes of DCD reveal performance differences in a series of cognitive-motor or perceptual-motor measurement [46]. Subtypes differ in relation to the co-morbidity [47]. Co morbidity is particularly high in children with generalized perceptual-motor or cognitive-motor disorder. This finding is important because the presence or absence of associated features directly associated with subtyping. The disorder is better understood if we know why the co-morbidity is associated with a particular [46].

Many studies have examined the relationship of clumsiness with hyperactivity, learning disabilities and attention disorders. These developmental problems are associated with cognitive dysfunction brain [46]. The survey shows that disorders in attention, language, reading and/or dyslexia often coexist with symptoms of clumsiness [48-59]. On the other hand, DCD is associated with many comorbid problems [60], including learning disabilities [61] and attention deficit disorder [62].

The most commonly observed element is the heterogeneity of the population with DCD [1,3,5,60,63-67]. From the past it has been recognized that there is no a standard profile of children with clumsiness [63]. There is no distinct motor profile performance describe all children with clumsiness. The certain is that the perceptual and cognitive- motor and fine motor development as well balance play an important role in motor performance.

Because they form a heterogeneous group, need more specific training and individualized instruction [3]. The task-specific instruction as intervention method has been used successfully in children with motor disabilities [68,69].

Longitudinal studies have highlighted associated problems, such as learning, behaviour, social and emotional adjustment, that children with coordination deficits are made up of distinctive subtypes either in type (or quality) of impairment; severity of coordination deficit; aetiology/history, and/or overlap with other conditions, and that these subgroups may require different intervention strategies [2]. The Green et al. study highlighted the complexity of coordination disorders and

considered whether there were substantive subtypes of coordination impairment that warrant differential interventions. Researchers suggested that another approach to consider the heterogeneous nature of DCD may be to analyze the interaction of strengths and weaknesses in perceptual and cognitive skills, along with developmental and environmental factors. Identifying the interaction between a child's strengths and weaknesses and particular environmental factors will be an important step forward in understanding the complexity and overlap of developmental disorders [2].

A meta-analysis of dual-task studies emphasized the role of high-order cognitive systems in gait control [70]. The main purpose of this meta-analysis review was to quantitatively assess cognitive interference on gait performance during normal walking as measured by dual-task methodology. Researchers reviewed experimental single group studies that measured gait performance with and without performing concurrent cognitive task. They suggested that the interaction between gait and cognitive functions would be useful for both researchers and professionals to plan appropriate interventional trials and inform clinical decision-making.

Age-related changes have been reported in cognitive and motor systems. Therefore, the increased cognitive motor interference (CMI) while walking with aging may be attributed to parallel age-related changes in cognitive and motor systems.

Changes in speed and the relationship between age and CMI effect on gait. Also, the relationship between the level of cognitive state and CMI effects on gait. Both are relevant for understanding gait control mechanisms. Researchers concluded that standardizing research methodology, as well as improving their ecological validity, enable better understanding of dual-task-related gait changes in different population and improves our understanding of their neural mechanisms and gait control in general [70].

In a clinical population with DCD co morbidity tends to be the rule rather than the exception. The classification of the disorder provides useful information about associated symptoms examining the comorbidity profile. Corresponding classification could be studied in children with other developmental disorders studied in a regular classroom (such as attention and hyperactivity disorder or learning difficulties).

It was important to classify children with DCD by taking a representative sample of the general pupil population (rather than a clinical population or individually from the DCD population).

Because of the representativeness of the sample, the results of our study could be generalized and contribute to the identification of rationale factors and interference.

Classification of children with DCD will assist to formulate specific assumptions about etiology or educational intervention.

According to the literature, studies seeking a causal explanation use samples representative of the total population (with and without disorder). In addition, cluster analysis seems to be a crucial statistical method in understanding the etiology or the treatment of a disorder [4].

In the present study, the classification of children with and without DCD has highlighted subgroups that have experienced specific disruptions in the motor and cognitive field. This classification was based on cognitive neuropsychological theory, which contributes to: a) initial selection of variables, b) interpretation of the results, so that the

structure of the subgroups can confirm or refute the theoretical position [4], and c) design intervention programs with specific instructional methods. Subgroups confirmed the cognitive neuropsychological model in the present study. Motor abilities or weaknesses were directly related to cognitive abilities or weaknesses that could predict academic performance. This important finding was shown in the DCD population (cluster 1, cluster 2, cluster 5, cluster 6), where the severity of motor and cognitive problems differed, but also in non DCD population (cluster 2, cluster 3), who did not faced motor and cognitive problems.

By categorizing children with and without DCD, cluster analysis revealed common dysfunction profiles both in motor and cognitive levels.

By revealing subgroups, the following conclusions were two-fold: a) the classification of children with motor coordination problems; and b) the early detection of learning disabilities from pre-school age, with the cognitive-motor factor as a precursor of these difficulties.

References

1. Dewey D, Kaplan BJ (2009) Subtyping of developmental motor deficits. *Dev Neuropsychol* 10: 265-284.
2. Green D, Chambers ME, Sugden DA (2008) Does subtype of developmental coordination disorder count: Is there a differential effect on outcome following intervention? *Hum Mov Sci* 27: 363-382.
3. Hoare D (1994) Subtypes of developmental coordination disorder. *Adapt Phys Activ Q* 11: 158-169.
4. Macnab JJ, Miller LT, Polatajko HJ (2001) The search for subtypes of DCD: Is cluster analysis the answer? *Hum Mov Sci* 20: 49-72.
5. Wright HC, Sugden DA (1996b) The nature of developmental coordination disorder: Inter and intra group differences. *Adapt Phys Activ Q* 13: 358-374.
6. Sugden DA, Wright HC (1998) *Motor coordination disorders in children*. USA: Sage Publications Inc.
7. Hoare D (1991) *Classification of movement dysfunctions in children: Descriptive and statistical approaches*. Unpublished doctoral dissertation, University of Western Australia, Perth, Australia.
8. Miyahara M (1994) Subtypes of students with learning disabilities based upon gross motor functions. *Adapt Phys Activ Q* 11: 368-382.
9. Wright HC, Sugden DA (1996a) A two-step procedure for the identification of children with developmental coordination disorder in Singapore. *Dev Med Child Neurol* 38: 1099-1106.
10. Piek JP, Baynam GB, Barrett NC (2006) The relationship between fine and gross motor ability, self-perceptions and self-worth in children and adolescents. *Hum Mov Sci* 25: 65-75.
11. Das JP, Naglieri JA, Kirby JR (1994) *Assessment of cognitive processes: The PASS theory of intelligence*. Boston, London, Toronto: Allyn and Bacon.
12. Naglieri JA, Das JP (2005) Planning, attention, simultaneous, successive (PASS) theory: A revision of the concept of intelligence. In D. P. Flanagan P, L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* New York: Guilford Press: 120-135.
13. Koutsouki D, Asonitou K (2015) Cognitive processes in children with Developmental Coordination Disorder. In Papadopoulos TC, Parrila RK, Kirby JR (Eds.), *Cognition, Intelligence and Achievement* London, USA: Elsevier: 267-289.
14. Naglieri JA, Das JP (1997a) *Cognitive Assessment System*. Itasca, IL: Riverside Publishing.
15. Imbens GW, Lancaster T (1996) Efficient estimation and stratified sampling. *J Econom* 74: 289-318.
16. Henderson SE, Sugden DA (1992) *Movement assessment battery for children*. London: The Psychological Corporation Ltd.

17. American Psychiatric Association (APA) (1994) Diagnostic and statistical manual of mental disorders (4th Ed) Washington, DC: Author. 37-55.
18. Kourtessis T, Tzetzis G, Kioumourtoglou E, Mavromatis G (2001) The effects of an intensive recreational program on children with movement difficulties. *New Zealand J Disabil Stud* 9: 120-139.
19. Pless M, Carlsson M, Sundelin C, Persson K (2002) Preschool children with developmental coordination disorder: a short-term follow-up of motor status at seven to eight years of age. *Acta Paediatr* 91: 521-528.
20. Rösblad B, Gard L (1998) The assessment of children with Developmental Coordination Disorders in Sweden: A preliminary investigation of the suitability of the movement ABC. *Hum Mov Sci* 17: 711-719.
21. Schoemaker MM, van der Wees M, Flapper B, Verheij-Jansen N, Scholten-Jaegers S, et al. (2001) Perceptual skills of children with developmental coordination disorder. *Hum Mov Sci* 20: 111-133.
22. Smits-Engelsman, BCM, Henderson SE, Michels CG (1998) The assessment of children with Developmental Coordination Disorders in Netherlands: The relationship between the Movement Assessment Battery for Children and the Körperkoordinations Test für Kinder. *Hum Mov Sci* 17: 699-709.
23. Smyth MM, Mason UC (1998) Use of proprioception in normal and clumsy children. *Dev Med Child Neurol* 40: 672-681.
24. Asonitou K, Koutsouki D, Skordilis M (2004) Differences in cognitive abilities between kindergarten students with and without DCD. Proceedings in 2004 Pre-Olympic Congress, Volume I (Lectures-Orals), 6-11 August, Aristotle University of Thessaloniki, Thessaloniki, Greece.
25. Asonitou K (2007) Assessment of cognitive-motor skills as a means of classification of students with and without developmental coordination disorder: Early detection of learning disabilities in preschool age. Published doctoral dissertation. Panteion University, Department of Psychology, Athens, Greece.
26. Bruininks R (1978) The Bruininks-Oseretsky Test of motor proficiency. Circle Pines, MN: American Guidance Service.
27. Naglieri JA, Das JP (1997b) Cognitive Assessment System administration and scoring manual. Itasca, IL: Riverside Publishing.
28. Asonitou K, Koutsouki D (2016) Cognitive process-based subtypes of developmental coordination disorder (DCD). *Hum Mov Sci* 47: 121-134.
29. Milligan GW, Cooper MC (1987) Methodology Review: Clustering Methods. *Appl Psychol Meas* 11: 329-354.
30. Morris PR, Blashfield R, Satz P (1981) Developmental classification of reading disabled children. *J Clin Exp Neuropsychol* 8: 371-392.
31. Hooper SR, Willis WG (1989) Learning disability subtyping. New York: Springer-Verlag.
32. Bender WN, Golden LB (1990) Subtypes of students with learning disabilities as derived from cognitive, academic, behavioral, and self-concept measures. *Learn Disab Q* 13: 183-194.
33. Zwicker JG, Missiuna C, Harris SR, Boyd LA (2012) Developmental coordination disorder: A review and update. *Eur J Paediatr Neuro*, 16: 573-581.
34. Thomas JR, Nelson JK (2003) Methods of research into physical activity. Athens: Medical Publications Paschalides.
35. Tabachnick BG, Fidell LS (2001) Using multivariate statistics (4th ed) Boston, MA: Allyn and Bacon.
36. Morris RD, Fletcher JM (1988) Classification in neuropsychology: A theoretical framework and research paradigm. *J Clin Exp Neuropsychol* 10: 640-658.
37. Norusis M (2011) IBM SPSS Statistics 19 Guide to data analysis. Pearson, UK: SPSS Inc.
38. Huberty CJ, Morris JD (1989) Multivariate analysis versus multiple univariate analyses. *Psychol Bull* 105: 302-308.
39. Wall AET (2004) The developmental skill-learning gap hypothesis: Implications for children with movement difficulties. *Adapt Phys Activ Q* 21: 197-218.
40. Das JP, Kirby J, Jarman RF (1975) Simultaneous and successive syntheses: An alternative model for cognitive abilities. *Psychol Bull* 82: 87-103.
41. Das JP, Kirby J, Jarman RF (1979) Simultaneous and successive cognitive processes. New York: Academic Press.
42. Cantell MH, Ahonen TP, Smyth MM (1994) Clumsiness in adolescence: Educational, motor, and social outcomes of motor delay detected at 5 years. *Adapt Phys Activ Q* 11: 115-129.
43. Geuze R, Börger H (1993) Children who are clumsy: Five years later. *Adapt Phys Activ Q* 10: 10-21.
44. Visser J (1998) Clumsy adolescents: A longitudinal study on the relationship between physical growth and sensorimotor skills of boys with and without DCD. Unpublished dissertation, University of Groningen, Holland.
45. Visser J, Kalverboer AF, Geuze RH (1998) The relationship between physical growth, movement experience and motor skills in adolescence: Differences between children with DCD and controls. *Hum Mov Sci* 17: 573-608.
46. Visser J (2003) Developmental coordination disorder: a review of research on subtypes and comorbidities. *Hum Mov Sci* 22: 479-493.
47. Kaplan BJ, Wilson BN, Dewey D, Crawford SG (1998) DCD may not be a discrete disorder. *Hum Mov Sci* 17: 471-490.
48. Dewey D, Kaplan BJ, Crawford SG, Wilson BN (2002) Developmental coordination disorder: Associated problems in attention, learning, and psychosocial adjustment. *Hum Mov Sci* 21: 905-918.
49. Dewey D, Wilson BN, Crawford SG, Kaplan BJ (2000) Comorbidity of developmental coordination disorder with ADHD and reading disability. *J Int Neuropsychol Soc* 6: 152-162.
50. Gillberg C, Kadesjo B (1998) ADHD and developmental coordination disorder. In T.E. Brown (Ed.) Attention deficit disorders and comorbidities in children, adolescents and adults. Washington DC: American Psychiatric Press.
51. Gillberg C, Kadesjo B (2000) Attention-deficit/hyperactivity disorder and developmental coordination disorder. In T.E. Brown (Ed.), Attention-deficit disorders and comorbidities in children, adolescents and adults (pp. 393-406). Washington DC, US: American Psychiatric Publishing, Inc.
52. Hill EL (2001) Non-specific nature of specific language impairment: A review of the literature with regard to concomitant motor impairments. *Int J Lang Commun Disord* 36: 149-171.
53. Kadesjo B, Gillberg C (1999) Developmental coordination disorder in Swedish 7-year-old children. *J Am Acad Child Adolesc Psychiatry* 38: 820-828.
54. Kadesjö B, Gillberg C (2001) The comorbidity of ADHD in the general population of Swedish school-age children. *J Child Psychol Psychiatry* 42: 487-492.
55. Kaplan BJ, Crawford SG, Wilson BN, Dewey D (1997) Comorbidity of developmental coordination disorder and different types of reading disability. *J Int Neuropsychol Soc* 3: 54-64.
56. Landgren M, Kjellman B, Gillberg C (1998) Attention deficit disorder with developmental coordination disorders. *Arch Dis Child* 79: 207-212.
57. Martini R, Heath N, Missiuna C (1999) A North-American analysis of the relationship between learning disabilities and developmental coordination disorder. *Int J Learn Disabil* 14: 46-58.
58. Piek JP, Pitcher TM, Hay DA (1999) Motor coordination and kinaesthesia in boys with attention deficit-hyperactivity disorder. *Dev Med Child Neurol* 41: 159-165.
59. Wilson PH, McKenzie BE (1998) Information processing deficits associated with developmental coordination disorder: A meta-analysis of research findings. *J Child Psychol Psychiatry* 39: 829-840.
60. Henderson SE, Hall D (1982) Concomitants of clumsiness in young children. *Dev Med Child Neurol* 24: 448-460.
61. Lazarus JCA (1990) Factors underlying inefficient movement in learning disabled children. In G. Reid (Ed.), Problems in movement control North-Holland: Elsevier: 241-279.
62. Landgren M, Petterson R, Kjellman B, Gillberg C (1996) ADHD, DAMP and other neurodevelopmental/psychiatric disorders in 6-year-old

-
- children: Epidemiology and co-morbidity. *Dev Med Child Neurol* 38: 891-906.
63. Gordon N, McKinlay I (1980) Who are clumsy children? In N. Gordon, I. McKinlay (Eds.), *Helping clumsy children*, 1-20. U.K., Edinburgh: Churchill Livingstone/U.K.: Longman Group Ltd.
64. Hulme C, Lord R (1986) Clumsy children: A review of recent research. *Child Care Health Dev* 12: 257-269.
65. Lyytinen H, Ahonen T (1988) Developmental motor problems in children: A 6-year longitudinal study. *J Clin Exp Neuropsychol* 10: 57-67.
66. Polatajko HJ (1999) Developmental coordination disorder (DCD): Alias the clumsy child syndrome. In Whitmore K, Har H, Willems G (Eds). *A Neurodevelopmental approach to specific learning disorders*. London: Mac Keith Press 119-133.
67. Taylor MJ (1990) Marker variables for early identification of physically awkward children. In G Doll-Tepper, C Dahmas, BH Doll, H von Selzam (Eds.), *Adapted physical activities-An interdisciplinary approach*. Proceedings of the 7th International Symposium, Berlin: Springer-Verlag 379-386.
68. Pless M, Carlsson M (2000) Effects of motor skill intervention on developmental coordination disorder. A meta-analysis. *Adapt Phys Activ Q* 17: 381-401.
69. Revie G, Larkin D (1993) Task-specific intervention with children reduces movement problems. *Adapt Phys Activ Q* 10: 29-41.
70. Al-Yahya E, Dawes H, Smith L, Dennis A, Howells K, et al. (2011) Cognitive motor interference while walking: a systematic review and meta-analysis. *Neurosci Biobehav Rev* 35: 715-728.