Role of visual–perceptual skills (non-motor) in children with developmental coordination disorder

Chia-Liang Tsai a, Peter H. Wilson b, Sheng K. Wu c,*

a Institute of Physical Education, Health and Leisure Studies, National Cheng Kung University, Taiwan
b School of Health Sciences, RMIT University, Australia
c Institute of Athletics, National Taiwan College of Physical Education, Taichung 404, Taiwan

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Abstract

The purposes of this study were to examine test–retest reliability of the Test of Visual–Perceptual Skills (Non-Motor)-Revised (TVPS-R), to explore motor-free visual–perceptual skills, and to categorize subtypes thereof in children with developmental coordination disorder (DCD). One hundred and seventy-eight children, aged 9 and 10 years, identified as having DCD with the Movement Assessment Battery for Children (M-ABC), were assessed, along with 200 typically developing children. The results showed good test–retest reliability for the total perceptual quotient scores of the TVPS-R, but not for all subtests. Children with DCD performed significantly poorer compared to typically developing children on the visual–perceptual test, but the deficits were not common to all children with DCD. This study supported the stance that we should consider the heterogeneous characteristics of children with DCD when designing experimental studies or developing educational interventions.

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Keywords: Developmental coordination disorder; Visual perception; Subtype

1. Introduction

Developmental coordination disorder (DCD) in the diagnostic and statistical manual of mental health disorder (DSM-IV) is a term describing motor impairment in the absence of
neurological disease, any known physical disorder, developmental delay, mental retardation, and low IQ (American Psychiatric Association, 1994). By definition, DCD interferes significantly with the child’s academic achievement, daily living skills (like dressing, tying shoelaces, and brushing teeth), and ability to engage in sporting activities. Contrary to the belief shared by numerous physicians, teachers, and parents that most children with DCD will grow out of their motor clumsiness, DCD has been shown to often persist into adolescence and early adulthood, along with associated psycho-social problems (Cantell, Smyth, & Ahonen, 1994; Visser, Geuze, & Kalverboer, 1998). In some cases, the motor impairments exhibited by children with DCD may increase; however, this pattern is variable (Inder & Sullivan, 2005).

Many studies have demonstrated that children with DCD display deficits on perceptual-motor functioning (Bonifacci, 2004; Henderson, Barnett, & Henderson, 1994; Hulme, Biggerstaff, Moran, & McKinlay, 1982; Hulme, Smart, & Moran, 1982; Lord & Hulme, 1987, 1988; van Waavelde, de Weerdt, de Cock, & Smits-Engelsman, 2004; Wilson & McKenzie, 1998). These visual–perceptual deficits can negatively impact children’s ability to conduct simple, everyday activities which require fine manipulation of objects, such as writing or drawing (Parush, Yochman, Cohen, & Gershon, 1998; Rosenblum, 2006). However, in terms of motor-free visual–perceptual ability, some studies have found conflicting results. Sigmundsson, Hansen, and Talcott (2003) found that children with DCD showed impaired visual sensitivity, but Bonifacci (2004) did not.

Visual perception is an intricate system that is concerned with both object identity and localization in space, and is intimately connected with action systems (Jeannerod, 2006). Visual perception relies on the integrity of the posterior visual pathway and cortical networks emanating from the occipital lobe (Lieberman, 1984). The so-called dorsal stream radiates from occipital cortex to posterior parietal cortex and is intimately concerned with object localization and action planning, while the ventral stream, radiating toward the superior temporal cortex, is concerned mainly with object identity. The two streams of processing interact in a complex way to inform action planning in 3D space. The visual–perceptual system per se is regarded as the dominant modality for controlling goal-directed actions (Hudgins, 1977; Jeannerod, 2006). Deficits in processing visual signals at various points along this network can lead to problems in movement planning, on-line movement correction, and feedback control (Wilson & McKenzie, 1998).

In children, the ability of visual perception is a developing process. The visual discrimination of young children develops rapidly over childhood and approaches adult levels at around 11–12 years of age (Atkinson & Braddick, 1989; Birch, & Lefford, 1967). Indeed, by 9 years of age, visual–perceptual skills are quite well refined. For example, figure-ground perception improves rapidly between 3 and 5 years, and stabilizes between the ages of 8 and 10 years; the ability of position in space develops completely around ages 7 to 9; the ability of form constancy rapidly improves from 6 to 7 years old, and achieves a stable condition at about 8 to 9 years, while the ability to discern more complex spatial relations shows consistent improvement over childhood and is well developed by 10 years of age (Atkinson, & Braddick, 1989; Williams, 1983). Taken together, visual perception is very well developed in middle childhood and reaches adult levels at around 12 years.

Numerous studies suggest that children with DCD have deficits in their perceptual-motor and visual–perceptual skills (Wilson & McKenzie, 1998). However, we know little about individual profiles of performance across tasks in children with DCD, or the proportion of children who deviate from the norm (Schoemaker et al., 2001). Hence, by exam-
ining a large number of children, the detailed data may be able to clearly reveal the severity of the individual visual–perceptual deficits in children with and without DCD.

DCD, despite a generalized impairment in nearly all areas of motor performances, shows considerable variation in the degree and pattern of perceptual-motor deficits (Hoare, 1994; Macnab, Miller, & Polatajko, 2001; Wright & Sugden, 1996), associated psycho-social difficulties (Cantell et al., 1994), and medical co-morbidity (Kaplan, Wilson, Dewey, & Crawford, 1998). Therefore, some studies (Hoare, 1994; Macnab et al., 2001) have suggested that a subgroup based on overall gross motor difficulty may be too general. Hoare (1994), for example, found a subtype of children with DCD suffering from a generalized visual dysfunction. In order to come to a better understanding of the etiology and prognosis of DCD, an awareness of the existence and nature of subtypes is required (Visser, 2003).

A statistical clustering approach to subtyping can provide insight into the specific perceptual-motor difficulties experienced by children with DCD and, ultimately, propose the appropriate intervention specific to the deficit (Hoare, 1994; Wright & Sugden, 1996). Using the same data set, the cluster approach can generate different subgroups based on different clustering algorithms. However, the stability of the cluster solution is quite sensitive to the overall sample size. Hair, Black, Babin, Anderson, and Tatham (2006) suggested that a ratio of 20 observations for each predictor variable is enough to make the results stable. Although some authors have queried the use of clustering techniques as a way of identifying subtypes of DCD (Kaplan et al., 1998), Macnab et al. (2001) clearly demonstrated the validity and potential of cluster analysis. They reported similarities between their subtypes of DCD and those of Hoare study (1994), and suggested using the approach to explore the characteristics and differences between source populations. In short, further categorization of children with DCD can increase our understanding of the aetiology and treatment of the condition (Macnab et al., 2001).

Although a few studies have explored the subtypes of DCD children, there are discrepant findings in the literature. It is not known whether these inconsistent findings are due to sample variations or different measurement tools. For example, sampling included both DCD and borderline DCD children in Hoare’s (1994) and Wright and Sugden’s (1996) studies, while both DCD and learning-disabled children were used in Miyahara (1994). The screening instruments included the MAND (McCarron Assessment of Neuromuscular Development) (Hoare, 1994), M-ABC checklist (Wright & Sugden, 1996), or Bruninks-Oseretsky Test of Motor Proficiency (BOTMP) (Macnab et al., 2001; Miyahara, 1994). In addition, the variables selected in the cluster analysis, the statistical approaches applied to subtyping, and the age range of the children who were assessed were different in all the above-mentioned studies, which all contributes to the variability of findings.

The test battery TVPS-R (Gardner, 1996) is an instrument used to assess visual–perceptual ability without motor skills being involved. For children with motor problems (e.g., DCD children), the TVPS-R is an appropriate tool to explore information processing ability. However, to date no data on the test–retest reliability of TVPS-R is available for children with DCD. Moreover, because there is high co-morbidity between DCD and other developmental disorders (e.g., learning disability and Attention Deficit/Hyperactivity Disorder) (Kaplan et al., 1998), some children with DCD who exhibit poor attentional control and concentration are less likely to be representative of their specialized groups which would influence the reliability of visual–perceptual performances. In addition, although norms for the TVPS-R have been established on children from diverse racial and ethnic
groups living in the United States, different cultural and environmental experiences in Tai-
wan are likely to influence visual–perceptual performance (Zimbardo, 1992). Taking these
issues into account, the reliability of the TVPS-R for use on children with DCD requires
further investigation.

The main objectives of this study were to (1) examine the test–retest reliability of the
TVPS-R when applied to Taiwanese children, both typically developing and with DCD;
(2) determine, in a large sample of children, whether there were differences in (non-motor)
visual–perceptual performance between typically developing and DCD children aged 9 to
10, and to explore the seriousness of the individual visual–perceptual deficits in DCD; and
(3) further explore subtypes of DCD using a statistical clustering approach and the impli-
cations of these subtypes for intra- and inter-group comparison.

2. Methods

2.1. Participants

All children (N = 1266), ranging in age from 9 to 10 years, were recruited from five
school districts located in different geographical locations in Taiwan and were attending
mainstream classrooms. Stratified random selection was the method used for sampling
in this study. None of the children had any definite signs of neurological damage, physical
or behavioral problems, or special needs in education that would disqualify him/her from
this study. Each child had a full-scale IQ-score above 70 on the WISC-R.

Children were screened using the M-ABC test (Henderson & Sugden, 1992) and cate-
gorized into one of three groups: normal (n = 692), borderline (n = 396), and DCD
(n = 178) groups. One hundred and seventy-eight children (75 boys and 103 girls) were
identified as having DCD (Total Impairment Score (TIS) on the M-ABC below the 5 per-
centile; Mean = 16.94; SD = 3.04). The Control group was randomly selected from the
larger sample and comprised 200 typically developing children (107 boys and 93 girls),
with a TIS above the 15%tile cutoff point (Mean = 5.38; SD = 2.62). The mean chronolog-
ical ages for the typically developing children was 10 years 6 months (SD = 2 months), and
for the DCD group was 10 years 3 months (SD = 3 months).

The population-based study was approved by the Ethical Committee of the Medical
Faculty of the National Cheng-Kung University in Taiwan and written consent was
sought from children’s parents.

2.2. Measuring instruments

2.2.1. Movement Assessment Battery for Children (M-ABC) (Henderson & Sugden, 1992)

The M-ABC test is designed to identify children with motor coordination problems.
According to a descriptive survey by Miller, Missiuna, Macnab, Malloy-Miller, and Polat-
ajko (2001), the M-ABC is the most commonly used instrument to identify children with
DCD aged from 4 to 12 years, and is a formal standardized normative motor-test instru-
ment that provides both a qualitative and quantitative evaluation of the child’s motor
competence in a wide range of tasks associated with his/her daily life. According to the
manual, the median percentage of agreement for impairment scores on the items was
between 80% and 90% at different age bands, and the overall reliability of the M-ABC
is considered to be good (Henderson & Sugden, 1992). In addition, Chow and Henderson
(2003) reported that inter-rater and test–retest reliabilities of the M-ABC for Chinese pre-
school children were excellent, with a mean intraclass correlation of .96 and .77,
respectively.

The M-ABC contains eight items in any one of four age bands (4 to 6, 7 to 8, 9 to 10,
and 11 to 12 years). The eight items for the 9–10 Age Band are: shifting pegs by rows,
threading nuts on bolts, and flower trail (manual dexterity); two-hand catch and throwing
bean bag into box (ball skills); one-board balance (static balance), hopping in squares, and
ball balance (dynamic balance). The TIS is the sum of converted raw scores on the eight
items and ranges from 0 to 40. This score summarizes performance on the test as a whole
and is interpreted in light of the percentile norm tables. By definition, a TIS below the 5%
cutoff point (i.e., $TIS \geq 13.5$) indicates a definite motor problem (or DCD); scores between
the 5% and 15% cutoff point (i.e., $10 \leq TIS < 13$) are categorized as Borderline DCD, and
scores above the 15% cutoff point (TIS < 10) indicate no significant motor impairment (viz
typically developing).

2.2.2. The Test of Visual–Perceptual Skills-Revised (non-motor) (TVPS-R)

The TVPS-R (Gardner, 1996) is designed to assess levels of visual–perceptual skills in
children aged between 4 years and 12 years, 11 months; it is a motor-free test and gender
neutral. This test does not require a verbal response and the forms are not language-
related. Normative scores were based on a group of 1032 typically developing American
children, including diverse racial and ethnic groups. The reliability coefficients of TVPS-
R for the total score ranged from .83 to .91 for each age level, giving acceptable internal
consistency (Gardner, 1996). The test consists of 112 items divided into seven subtests: (1)
Visual Discrimination (VD); (2) Visual Memory (VM); (3) Visual–Spatial Relationships
(VSR); (4) Visual-Form Constancy (VFC); (5) Visual–Sequential Memory (VSM); (6)
Visual Figure-Ground (VFG); and (7) Visual Closure (VC) (Gardner, 1996). The seven
subtests measure different but interrelated visual–perceptual abilities. Each subtest consists
of 16 items that are ordered by difficulty; each item uses a forced-choice procedure with
four or five options. A child is asked to verbally state or point to the correct response
out of either four or five choices. The total number of correct responses for each subtest
is tallied, yielding a raw score from 0 to 16. Each subtest raw score is converted into per-
centile ranks and scaled scores. The sum of all seven scaled scores can be converted into
perceptual quotients, giving the overall performance on the TVPS-R. Klein, Sollereder,
and Gierl (2002) have reported that the TVPS correlated in the low-to-moderate range
with intellectual tests. The inter-correlations between the subtests ranged from .34 to
.47, indicating that the subtests measure different aspects of visual perception (Gardner,
1996).

2.3. Procedure

The Chinese instructions of the M-ABC and TVPS-R tests used in this study were
established by one of the authors, a paediatric physiotherapist, through forward and back-
ward translation. For identifying and categorizing children into groups (typically develop-
ing and DCD), and for excluding borderline DCD, the M-ABC test was administered to
each child in the first session. A qualified elementary school teacher who was blind to the
group membership of these children then individually administered the TVPS-R using
standard procedures. Each child was seated and the test plates were placed flat on a table.
in a small, quiet classroom. The time required for each participant to complete the TVPS-R depended on whether he or she reached the ceiling for every subtest.

To examine test–retest reliability of the TVPS-R, 37 children with DCD (18 boys and 19 girls; M-ABC impairment scores 16.47 ± 3.32) and 64 typically developing children (30 boys and 34 girls; M-ABC impairment scores 6.48 ± 2.08) were randomly selected from the parent sample and tested on two separate occasions, with a 7-to-18-day interval (Mean = 12 days). For each child, both test and retest sessions were arranged at approximately the same time of day. The same tester administered both the test and retest.

2.4. Data analysis

The raw scores of subtests from the TVPS-R were converted to scaled scores and percentile ranks. The test–retest reliabilities were determined using the intraclass correlation coefficient (ICC). A coefficient below .40 was considered poor, .40–.59 fair, .60–.74 good and .75–1.00 excellent (Cicchetti, 1994). Standard errors of measurement were also used to facilitate comparison of reliability estimates.

Paired t-tests were carried out to determine any significant differences on the subtests scaled scores and total tests (i.e., perceptual quotients) with group (Control/DCD) as the between factor. Cohen’s d (Cohen, 1977) was used as an estimate of effect size for group comparisons; variability among effect size was attributed to random sampling error, since an inflated significant value could result for larger samples (Dindia & Allen, 1992). The following conventions outlined by Cohen (1977) were used to interpret the magnitude of mean effect size: \( d = .2 \) (small effect size), \( d = .5 \) (moderate effect size), and \( d = .8 \) (large effect size).

To further analyze the presence of visual–perceptual deficits in children with DCD, the proportion of children scoring in the clinical range, namely scores below the 15th percentile, was calculated for each subtest and the total score. This cut-off was determined on the basis of the normative values reported in the manual.

The standard score for each item on the M-ABC and the Visual–Perceptual Quotient for the TVPS-R were entered as exploratory variables in the cluster analysis. To enhance the validity of the cluster solution, a two-stage clustering method was used: a hierarchical agglomerative agglomerative procedure followed by a K-means iterative partitioning approach (Milligan & Cooper, 1987). The scores of eight items on the M-ABC test and the visual–perceptual quotient of TVPS-R were all converted into standardized scores (e.g., z scores), which were used as raw data for the cluster analysis. The first step was to determine how many clusters were in the DCD group by a hierarchical agglomerative procedure based on Squared Euclidean distance. A series of cluster analyses were used to determine the number of subtypes: i.e., average linkage, centroid clustering, and Ward’s method. Then, the K-means method with a process of continuous iterative adjustment was used to enhance the internal validity of the cluster solution. Finally, one-way ANOVA on the non-standardized scores for each of the motoric and visual–perceptual variables was used to compare the cluster groups and highlight their defining characteristics (Macnab et al., 2001). Post hoc tests were conducted using Scheffé’s method.

Descriptive values were presented as means and standard deviations. Results were considered statistically significant at \( p < .05 \). All data analyses were performed using the SPSS 11.5 statistical package.
3. Results

3.1. Test–retest reliability

Table 1 presents the ICCs, which were .88 and .82 for the total scores for the DCD and control groups, respectively, indicating excellent test–retest reliability. With respect to subtests, test–retest reliability was generally fair-to-good for both the DCD group (ICCs = .58–.75) and control group (ICCs = .50–.82); the value for the VC subtest (ICC = .82) was excellent for controls. The standard error of measurement (SEM = 8.8) for the total perceptual quotient scores was also satisfactory in the DCD group.

3.2. Inter-group comparison

The means, standard deviation, and effect size for children with DCD and typically developing children are presented in Table 2. Children with DCD performed significantly worse compared to typically developing children on each of the seven subtests from the TVPS-R and overall visual–perceptual performance. Differences between these two groups were most pronounced on the total score and the visual discrimination, visual form constancy, and visual closure subtests. Results showed a large effect size for the total scores on the TVPS-R, and generally large-to-medium effect size for the subtests; the one exception was a medium-to-small effect size for visual–spatial relationships.

Table 1
The intraclass correlation coefficients (ICCs) and standard errors of measurement (SEM) for test–retest reliability of the TVPS-R subtests scaled scores and total scores

<table>
<thead>
<tr>
<th></th>
<th>VD</th>
<th>VM</th>
<th>VSR</th>
<th>VFC</th>
<th>VSM</th>
<th>VFG</th>
<th>VC</th>
<th>Total scores</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DCD (N = 37)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICC</td>
<td>.74</td>
<td>.67</td>
<td>.75</td>
<td>.71</td>
<td>.58</td>
<td>.59</td>
<td>.72</td>
<td>.88</td>
</tr>
<tr>
<td>SEM</td>
<td>2.5</td>
<td>2.8</td>
<td>2.3</td>
<td>3.5</td>
<td>4.4</td>
<td>4.0</td>
<td>3.5</td>
<td>8.8</td>
</tr>
<tr>
<td><strong>Control (N = 64)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICC</td>
<td>.59</td>
<td>.50</td>
<td>.73</td>
<td>.61</td>
<td>.54</td>
<td>.60</td>
<td>.82</td>
<td>.82</td>
</tr>
<tr>
<td>SEM</td>
<td>2.9</td>
<td>3.3</td>
<td>2.7</td>
<td>4.1</td>
<td>4.0</td>
<td>3.1</td>
<td>3.3</td>
<td>12.1</td>
</tr>
</tbody>
</table>

VD: visual discrimination; VM: visual memory; VSR: visual–spatial relationships; VFC: visual-form constancy; VSM: visual–sequential memory; VFG: visual figure-ground; VC: visual closure.

Table 2
Means, standard deviations (in brackets) and effect size for the different subtests scaled scores and the perceptual quotients of TVPS-R test for each group

<table>
<thead>
<tr>
<th></th>
<th>Control (N = 200)</th>
<th>DCD (N = 178)</th>
<th>t</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual discrimination</td>
<td>10.53 (2.67)</td>
<td>8.61 (3.33)</td>
<td>6.15</td>
<td>&lt;.001</td>
<td>.6</td>
</tr>
<tr>
<td>Visual memory</td>
<td>10.35 (2.95)</td>
<td>8.90 (3.10)</td>
<td>4.63</td>
<td>&lt;.001</td>
<td>.5</td>
</tr>
<tr>
<td>Visual–spatial relationships</td>
<td>12.28 (2.23)</td>
<td>11.19 (3.03)</td>
<td>3.97</td>
<td>&lt;.001</td>
<td>.4</td>
</tr>
<tr>
<td>Visual-form constancy</td>
<td>10.24 (3.69)</td>
<td>7.92 (4.30)</td>
<td>5.61</td>
<td>&lt;.001</td>
<td>.6</td>
</tr>
<tr>
<td>Visual–sequential memory</td>
<td>10.81 (3.19)</td>
<td>8.93 (4.02)</td>
<td>4.98</td>
<td>&lt;.001</td>
<td>.5</td>
</tr>
<tr>
<td>Visual figure-ground</td>
<td>10.82 (2.94)</td>
<td>9.10 (4.00)</td>
<td>4.73</td>
<td>&lt;.001</td>
<td>.5</td>
</tr>
<tr>
<td>Visual closure</td>
<td>9.48 (4.03)</td>
<td>7.03 (4.21)</td>
<td>5.75</td>
<td>&lt;.001</td>
<td>.6</td>
</tr>
<tr>
<td>Perceptual quotient</td>
<td>104.51 (14.62)</td>
<td>91.69 (16.38)</td>
<td>7.99</td>
<td>&lt;.001</td>
<td>.8</td>
</tr>
</tbody>
</table>
The number of children with DCD who obtained scores for the seven subtests and total score in the clinical range (i.e., scores below the 15th percentile) on the TVPS-R are given in Table 3. Fifty-five (30.9%) children with DCD had a total score on the TVPS-R below the 15th percentile. Seventy-nine children with DCD (44.4%) appeared to have pronounced difficulties with visual closure, which was the task worst performed by the DCD group. Only 15 children with DCD (8.4%) scored within the clinical range on Visual–Spatial Relationships. For other subtests, about 21–34% of children with DCD obtained scores within the clinical range.

### 3.3. Intra-group comparison

Three methods of hierarchical cluster analysis — average linkage, centroid clustering, and Ward’s method — were used to determine the number of clusters. Each indicated four subtypes in the DCD group. Since the Ward’s method is considered the most appropriate (Milligan & Cooper, 1987), we adopted it for the subsequent analysis. After subsequent analysis using the K-means method with four cluster seeds, a total of 141 (80%) children with DCD were located in the same cluster when the Ward’s method was compared with the iterative method. More specifically, the smallest group, cluster 4, had identical members in these two methods.

In view of their stability and internal validity, the hypothesized subgroups were suitable for further investigation. One-way ANOVA was used to compare subtypes on the entered variables. This method was used to highlight the defining characteristics of each cluster. But, it should not be used as a means of hypothesis testing or validating the cluster solution (Macnab et al., 2001). In the current study, children with DCD formed four homogeneous subtypes who shared similar motoric and visual–perceptual characteristics. Children in cluster 4 were excluded from the post hoc analysis as their number was small. Seventy-one typically developing children were randomly selected from the original sample to form a comparison group. Table 4 shows the score differences for the nine tasks between the three subgroups and control group were all significant ($p < .001$). Pair-wise, post hoc, multiple-comparison analysis of these motoric and visual–perceptual data also yielded significant differences among these four groups.

Cluster 1 comprised the most children (62). The essential nature of this subgroup’s performance was above-average scores on ball skills relative to their DCD peers, while the rest of the motoric and perceptual tasks were below the average of the whole DCD group, the one exception being the ball-balance task.

Cluster 2 contained 51 children who performed better on visual perception and two dynamic balance tasks (hopping in squares and ball-balance) but whose performances on manual dexterity (with the exception of the flower-trail task), ball skills, and static bal-

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Table 3

<table>
<thead>
<tr>
<th></th>
<th>VD</th>
<th>VM</th>
<th>VSR</th>
<th>VFC</th>
<th>VSM</th>
<th>VFG</th>
<th>VC</th>
<th>Total scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>49</td>
<td>38</td>
<td>15</td>
<td>61</td>
<td>50</td>
<td>38</td>
<td>79</td>
<td>55</td>
</tr>
<tr>
<td>Percentage</td>
<td>27.52</td>
<td>21.34</td>
<td>8.43</td>
<td>34.27</td>
<td>28.09</td>
<td>21.35</td>
<td>44.38</td>
<td>30.90</td>
</tr>
</tbody>
</table>

VD: visual discrimination; VM: visual memory; VSR: visual–spatial relationships; VFC: visual-form constancy; VSM: visual–sequential memory; VFG: visual figure-ground; VC: visual closure.
Cluster 1 consisted of 62 children who exhibited the worst performance across all measures. Children in this cluster were characterized by significantly lower scores on the flower-trail task than those in clusters 2 and 3. Other than cluster 3, they also demonstrated relatively good performance on visual perception. Post-hoc pair-wise comparisons demonstrated a better score on this skill for cluster 2 than for cluster 1, and the performance was not significantly different from that of typically developing children.

Cluster 2 consisted of 51 children who exhibited significantly better performance on the flower-trail task than those in clusters 1 and 3. Other than cluster 3, they also demonstrated relatively good performance on visual perception. Post-hoc pair-wise comparisons demonstrated a better score on this skill for cluster 2 than for cluster 1, and the performance was not significantly different from that of typically developing children.

Cluster 3 consisted of 58 children who exhibited the best performance of all clusters on five items (e.g., static and dynamic balance abilities, and manual dexterity except for the flower-trail task). Children in this cluster performed significantly better on visual perception than those in cluster 1. These six tasks were all performed with above-average results relative to most of their DCD peers, in contrast to poor performance on the measures of ball skill, which were below average. Of the ball skills, post-hoc tests showed that this cluster performed worse than cluster 1 on the two-hand catch, only. No significant difference was found between this cluster and any other cluster on throwing a beanbag into a box. Children in this cluster performed significantly better than the children in clusters 1 and 2 on the static balance item. There was no significant difference between this cluster and control group for two items: shifting pegs by rows and visual perception.

Cluster 4 was the smallest group (seven children with DCD) who exhibited the greatest difficulty on the following four items: visual–perceptual ability, dynamic balance skills, and shifting pegs by rows. Children in this cluster were the only ones to perform poorly on the ball balance item.

4. Discussion

4.1. Test–retest reliability

If clinicians are going to use standardized tests to evaluate visual–perceptual function in participants with different cultural and environmental experiences, the reliability of the

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Analysis of variance for the impairment scores of eight items of M-ABC and visual-perceptual quotient of TVPS-R: mean value, standard deviation (in brackets) and post-hoc multiple comparisons for motoric and perceptual scores between four subtypes of DCD group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cluster 1</td>
</tr>
<tr>
<td></td>
<td>(N = 62)</td>
</tr>
<tr>
<td>M-1</td>
<td>0.89 (1.02)</td>
</tr>
<tr>
<td>M-2</td>
<td>4.11 (1.32)</td>
</tr>
<tr>
<td>M-3</td>
<td>4.53 (0.95)</td>
</tr>
<tr>
<td>B-1</td>
<td>1.16 (1.65)</td>
</tr>
<tr>
<td>B-2</td>
<td>1.98 (1.90)</td>
</tr>
<tr>
<td>S-1</td>
<td>3.76 (0.93)</td>
</tr>
<tr>
<td>S-2</td>
<td>1.25 (1.35)</td>
</tr>
<tr>
<td>S-3</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>VP</td>
<td>82.40 (16.25)</td>
</tr>
</tbody>
</table>

\(a\) Cluster 4 was excluded in the post-hoc multiple comparison; M-1: shifting pegs by rows; M-2: threading nuts on bolts; M-3: flower trail; B-1: two-hand catch; B-2: throwing bean bag into box; S-1: one-board balance; S-2: hopping in squares; S-3: ball balance; VP: TVPS-R quotient.
instruments used must be established beforehand (Benson & Clark, 1982). This is especially important since some children with DCD commonly show symptoms of comorbid conditions (Kaplan et al., 1998). Most importantly, up to now, no study has investigated the test–retest reliability of TVPS-R for children with DCD. On the whole, the TVPS-R scores on both the total test and the subtests had adequate stability over time. It is interesting to note that the test–retest reliability was found to be excellent for the total perceptual quotient scores in the DCD and typically developing groups, but not for all the subtests in these two groups. The primary results from the present study were that the TVPS-R was reliable for use in clinical settings. However, the scores on the subtests should be used with extreme caution for decision-making or treatment-intervention. Moreover, the finding that typically developing Taiwanese children generally scored below American norms in the TVPS-R test seems to reveal that cultural differences worthy of future study, and the use of standardized scores applied to local populations in clinical practice.

4.2. Inter-group comparison

In the present study, children with DCD performed poorly on visual–perceptual tasks. These findings were compatible with most recent studies (Henderson et al., 1994; Hulme, Biggerstaff et al., 1982; Hulme, Smart et al., 1982; Lord & Hulme, 1987, 1988; Parush et al., 1998; van Waelvelde et al., 2004; Wilson & McKenzie, 1998), but inconsistent with Bonifacci (2004), who claimed that children with different motor abilities only differed significantly on visual-motor integration tasks, but not on visual–perceptual performance. The test of TVPS-R requires the contributions of different cognitive functions (e.g., synthetic and analytic processing skills), memory capacity, and selective attention, but is also used predominantly to confirm diagnosis and to monitor change as a result of therapy (Bishop & Curtin, 2001). We argue that results provide a valid representation of their actual abilities and a referential index for intervention.

All TVPS-R subtests were significantly poorer in children with DCD than in typically developing children. The results of four measures were in agreement with several previous findings: visual discrimination (Henderson et al., 1994; Hulme, Biggerstaff et al., 1982; Hulme, Smart et al., 1982; van Waelvelde et al., 2004), visual–spatial relationships (Hulme, Smart et al., 1982; Schoemaker et al., 2001; Wilson & McKenzie, 1998), and visual-form constancy and visual figure-ground (Hulme, Biggerstaff, et al., 1982; Hulme, Smart, et al., 1982; Lord & Hulme, 1987, 1988). It is worth pointing out that, according to meta-analysis conducted by Wilson and McKenzie (1998), the greatest deficiency in visual–spatial processing in children with DCD existed regardless of whether or not the tasks involved a motor component. In addition, Sigmundsson and Hopkins (2005) indicated that there is a clear relation between poor performance on tests of visual closure (VC) and motor impairment. However, since the test–retest reliabilities of Visual–Sequential Memory and Visual Figure-Ground were only fair in this study, the results for these tests should be interpreted with caution.

In contrast to several recent studies, children with DCD also performed significantly poorer than typically developing children on both visual memory and visual–sequential memory. Dwyer and McKenzie (1994), for example, found that children with DCD did not differ from typically developing children for the reproduction of geometric patterns on immediate recall, but were significantly less accurate than typically developing children’s performance after a 15-s delay. However, children with DCD in this study, when
performing two tasks of visual memory and visual–sequential memory in the TVPS-R, appeared to be less proficient in memorizing a single form or a series of forms with the correct sequence under time pressure. As well, since visual–sequential memory was found to be one of the best predictors of handwriting speed (Tseng & Chow, 2000), the results in this study seem to suggest that poor manual performance would be compromised by poor visual–perceptual skills. However, Schoemaker et al. (2001) found two subtests (i.e., figure-ground perception and form constancy) of DTVP-2 did not reach significance. These contradictory findings are difficult to explain, because these two measures are comparable to visual–form constancy and visual figure-ground in the TVPS-R. Differences in sampling might explain the discrepancy: Schoemaker et al. (2001) recruited children with borderline DCD, aged 6–12 years.

Since some researchers (Schoemaker et al., 2001) have emphasized the importance of individual data-analysis and queried the clinical relevance of statistically significant differences, it is worth exploring this issue in our large sample of children with DCD. About thirty percent of children with DCD showed general problems on the TVPS-R measure, and around one-third failed four isolated subtests (e.g., VM, VFC, VSM, and VFG). Only around 8% of children with DCD obtained scores in the clinical range on the VSR subtest, compared with about 20% in the study of Schoemaker et al. (2001). Thus, children with DCD did not manifest serious visual–spatial deficits, notwithstanding Wilson and McKenzie’s (1998) suggestion that generalized visual–spatial deficits are common in DCD. In addition, about 44% of children with DCD appeared to experience specific problems on the visual-closure subtest which was comparable to the figure of 50% reported by Schoemaker et al. (2001). In addition, six children (one boy and five girls) in the DCD group had scores above the 85th percentile. This finding seems to be in agreement with van Waelvelde et al. (2004), who reported that not all children with DCD have visual–perceptual deficits.

Children with DCD performed significantly worse compared to typically developing children on the total TVPS-R score test. Reduced exposure to information-rich perceptual-motor tasks may contribute to this general pattern of deficit. Indeed, typical development involves reciprocal interplay between biological or maturational processes and learning opportunities afforded by the environment (Gilger & Kaplan, 2001). Perceptual learning and abilities can be improved through practical experience as the mobile infant/child learns to extract task-relevant information from the surroundings. Any factor that impacts a child’s willingness to explore their environment can impede this process. For example, lower perceived self-efficacy toward physical activities (Cairney, Hay, Faught, Mandigo, & Flouris, 2005) and reduced physical activity (Faught, Hay, Cairney, & Flouris, 2006) are frequently reported in DCD. Therefore, perceived adequacy toward physical activity is likely an important factor affecting the chances of perceptual learning.

Some studies (Ungerleider & Mishkin, 1982; Valyear, Culham, Sharif, Westwood, & Goodale, 2006) have suggested that visual object perception follows two different routes in the human brain: a ventral pathway, an occipital-temporal route that supports (view-invariant) object recognition and goal selection; and a dorsal pathway, an occipital-parietal route that supports (view-dependent) object-directed action (i.e., the orientation or spatial properties of an potential goal object, viz its location in space relative to the observer). Although the subtests of TVPS-R have not been clearly divided into these two distinct categories, visual closure (Sigmundsson & Hopkins, 2005) or visual discrimination could be linked to the ventral-visual stream, whereas visual–spatial relationships are more likely to be linked to the dorsal-visual stream. It is suggested here that children with DCD
have impaired visual sensitivity in both kinds of visual processing, which is in accordance with Sigmundsson et al.’s (2003) study. Interestingly, visual–perceptual deficits are associated with brain immaturity and lesions, one mechanism being reduced volume of the peritrigonal white matter (Koeda & Takeshita, 1992). The current finding seems to suggest that in children with DCD there may be an undiagnosed immaturity of brain networks that support complex visual–spatial processing and future study of those networks in DCD is warranted.

4.3. Intra-group comparison

Children in cluster 1 represented the most impaired of the DCD participants, with most motor and visuospatial skills below average when compared to the rest of the DCD samples. These cluster profiles were in accordance with those of Macnab et al. (2001), who demonstrated that one DCD cluster performed below their peers in the area of fine-motor skills (manual dexterity), visual-motor integration, and visual perception. Children in this cluster performed particularly well on ball skills and their impairment scores (<2) were between the 5th and 15th percentiles. This suggests that their visuospatial deficits were not of such severity as to interfere with the precise spatial-temporal demands of aiming and catching (Henderson & Sugden, 1992).

Children in cluster 2 were characterized by their superior visual–perceptual skill in comparison to the rest of the DCD subgroups, and their performance on this item was not significantly different from that of typically developing children. Notwithstanding the fact that children with DCD have shown visual–perceptual deficits in a number of previous studies, the performances of cluster 2 contradicted this since 28 of these children (54.9%) demonstrated above-average ability (i.e., scores above the 50th percentile). The result was consistent with the findings of Hoare (1994), who found neither visual perception nor visual-motor perception was an essential component of the disorder. This provided evidence against the notion of generalized visual dysfunction in DCD children. In addition, ANOVA revealed that there were significant differences on the flower-trail task between cluster 2 and each of the other subgroups. Indeed, their impairment score for manual dexterity was 0.67 (±0.84), above the 90th percentile; nearly all cluster-2 children (47 out of 51) performed manual skills normally under timed conditions.

Children in cluster 3 had six out of nine tasks above the average performance compared to the rest of the DCD subgroups. Children in this cluster performed better than children in clusters 1 and 2 on the static balance test. This finding is consistent with the results of Hoare (1994) and Macnab et al. (2001) who identified a cluster characterized by good performance, relative to peers, on a measure of static balance. Nevertheless, these children had particular difficulty in performing aiming and catching skills, which demand precise responses under high spatial demands. This result was in agreement with Wright and Sugden’s (1996) finding that one cluster of children needed particular help in performing throwing, aiming, and receiving skills. They found that some of the Singaporean DCD children demonstrated a dysfunction separate from other manipulative and functional tasks requiring visual integration. This was also evident in our study, where children in cluster 3 performed well on manual-dexterity tasks, but not on ball skills. Finally, no significant differences between this cluster and the control group were found for visual–perceptual performance.
Children in cluster 4 demonstrated the most obvious dysfunction of the four subgroups. Of those children with visual–perceptual skills in the clinical range (i.e., scores below the 15th percentile), five out of a total of six, were from cluster 4. This cluster also appeared to have the most generalized pattern of deficit on the M-ABC. In short, clinically significant deficits on the TVPS-R seem to be quite predictive of severe DCD.

In an attempt to further understand the nature of children with severe motor impairments and to narrow the variability of motor abilities, the source populations drawn into the cluster analysis in the current study involved only children with DCD, in contrast to the Hoare (1994) and Wright and Sugden (1996) who selected DCD and borderline DCD children. Our more stringent criteria is justified because a study with implications for intervention needs to ensure that samples clearly represent defined clinical populations (Macnab et al., 2001). In addition, we further confined our study to children in the 9–10 year range in order to limit threats to internal validity posed by highly heterogeneous samples; this age range corresponded to age band 3 on the M-ABC. Although the variables selected should ensure minimal overlap (Hooper & Willis, 1989), we believe that items from the same section of the M-ABC do represent distinct motor abilities. For example, the study found that children in cluster 2 or 3 demonstrated different manual fine-motor abilities. As well, our set of measures differed somewhat from earlier studies which partly explain points of divergence on the composition of subgroups.

Until now, very few experimental studies of DCD have controlled for visual–spatial factors that could pose a threat to internal validity (e.g., changes to stimulus characteristics or the mapping of stimulus-response parameters). In fact, when the nature of motoric and perceptual impairments presented by the whole DCD group in the present study was subtyped and compared statistically, in our study different motor and visual–perceptual characteristics appeared in every separate subtype. This finding once again underlined Hoare’s (1994) statement that children with DCD not only differed from their peers, but also had distinct motor and perceptual-motor performances among themselves. Our findings support the view that the identification of DCD subgroups is important not only for theoretical reasons, but also to aid diagnosis and to accurately identify and evaluate more specific intervention strategies (Visser, 2003; Wright & Sugden, 1996). In addition, the recognition that children with DCD represent an enormously heterogeneous group at visual–perceptual and motoric tasks also has important implications for educational interventions (Gilger & Kaplan, 2001). Future studies into DCD group should take the heterogeneous issue into account and administer an experimental design with more attention to control variables. Moreover, further longitudinal study should investigate possible transmigration among these different subtypes of DCD children.

5. Conclusions

The performance of children on visual–perceptual tests have implications for developing better remediation and intervention strategies, and for the performance of communicative, cognitive, and everyday tasks. The results of the current study showed that children with DCD obtained significantly lower scores than typically developing children on a motor-free test of visual perception. We also showed that while group differences in visual–perceptual abilities may be statistically significant, some of the children with DCD did not have general visual–perceptual dysfunction. The stability of the total scores of TVPS-R can be considered adequate as a referential guide for appropriate evaluation in
children with DCD. However, we need to be cautious in using subtest scores for decision-making or treatment-intervention, since children with DCD do indeed belong to a heterogeneous group.

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References


