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# Correlations between Performance in a Virtual Reality Game and the Movement Assessment Battery Diagnostics in Children with Developmental Coordination Disorder

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**Featured Application: The game score of a simple non-immersive VR game might be used for preliminary distinction between TD children and children with DCD and the hand path data may reflect upon specific impairments of the child, mainly in visual-motor coordination.**

**Abstract:** We aimed to compare the performance in a Virtual Reality (VR) game between Typically Developed (TD) children and children with Developmental Coordination Disorder (DCD). We then compared the performance in a VR game with the sub-grades of the Movement Assessment Battery for Children (MABC). Twenty TD children (10 boys; mean and SD age 5.1 ± 0.6) and 10 children with DCD (4 boys; mean and SD age 5.6 ± 0.6) participated in the study. The parents filled out the DCD questionnaire. The MABC was administered. Each subject stood on a pressure pad and played a non-immersive VR game. The game score, hand path length, and movement of center of pressure were recorded. The game score achieved by the control group was ~22% higher compared to the game score achieved by the research group ($p = 0.042$). The path length of the right hand strongly correlated with the visual-motor coordination MABC subcategory score ($r = 0.902$, $p < 0.001$), with the balance MABC subcategory score ($r = 0.769$, $p = 0.009$), and with the total MABC score ($r = 0.667$, $p = 0.035$). This VR game might provide a preliminary distinction between TD children and children with DCD. Furthermore, investigation of hand path length may reflect the visual-motor coordination impairment of the child.

**Keywords:** kinematics; center of pressure; visual motor coordination

## 1. Introduction

Children with Developmental Coordination Disorder (DCD) have difficulty with fine and/or gross motor coordination [1,2]. Their clumsiness may cause difficulties in performing activities of daily living, e.g., dressing up and eating with utensils. Consequently, they tend to limit their participation in physical activities in early childhood and beyond [3]. These motor deficiencies may have mental, behavioral, and social consequences, affecting the quality of life of the child [4–6].

It has been recently suggested that it would be useful to understand DCD as a deficit in the perception–action relationship, in the context of the demands of the task, and the understanding of the child of his or her own action capabilities [7]. This view emphasizes the need for a comprehensive evaluation method of the difficulties faced by the child. Current common tools for diagnosis include questionnaires filled out by parents, e.g., the Developmental Coordination Disorder Questionnaire (DCDQ), or by teachers, e.g., the motor skill checklist [8]. Actual physical evaluation of the child may be performed using the Movement Assessment Battery for Children (MABC). The MABC is a norm-referenced assessment used to determine the presence of DCD by means of three subsections of manual dexterity, ball manipulation skills, and static and dynamic balance [9,10]. A strong correlation was found between the motor skill checklist and the MABC [8]. As technology evolves, more accurate and user-engaging tools are proposed to evaluate and treat children with motor difficulties.

Non-immersive Virtual Reality (VR) systems have been used to examine the quality of motor patterns of children with DCD [11], and also as an intervention tool for children with DCD [12–15], as well as other populations, e.g., children with Cerebral Palsy [16]. Recently, Gonsalves et al. [17] found that 10–12-year-old children with DCD had a slower hand path speed, greater wrist extension, and greater elbow flexion than Typically-Developed (TD) children, while playing VR games. It was suggested by the authors that the deficiency in feedback processes in children with DCD may be aided through the feedback mechanisms that VR systems offer, e.g., cognitive feedback of the score, as well as auditory feedback and visual feedback. However, this interesting finding has not been explored in younger children with DCD. An earlier evaluation of the condition of the child may enable earlier intervention tailored to the child's needs. Another benefit of VR systems is that they might allow for the computerized recording of kinematics and kinetics data of the player while engaged in the game activity, so that using expensive, stationary motion capture systems and taping markers to track the child's hand movement may not be required. For example, it has been shown that the Wii balance board is a reliable assessment device for recording the movement of the Center of Pressure (COP), as a mean for evaluating balance disorders [18]. The simplicity and availability of inexpensive commercialized VR systems may prove to be an important tool for the early evaluation of different aspects of motor awkwardness in young children with DCD. In this study, we concentrated on a young population of children and incorporated a simple mobile VR system, designed for young children. It acquires kinematic data without the need for an external measurement device.

We aimed to (a) compare the performance between TD children and children with DCD in the VR game, and (b) explore the correlations between the performance in the VR game and the grades in sub-categories of the MABC in children with DCD. The performance in the VR game was quantified using the game score, the ranges and path length of the COP movement, and the path lengths of each hand. While we hypothesized that the manual dexterity and visual-motor coordination scores would correlate with the VR parameters (game score and hand path length), we did not expect the game to detect balance impairment. For this reason, we added recordings of COP during the gaming trials, which we hypothesized would correlate with the balance scores of the MABC. These parameters were therefore chosen to gain a better understanding of similarities between playing the VR game and undergoing evaluation via the MABC.

## 2. Methods

### 2.1. Participants

Thirty children aged 4–6 years old participated in the study: ten children with DCD (diagnosed by a physician) enrolled using a list of children referred to the Weinberg child development center in the Sheba medical center. Also, 20 age-matched TD children enrolled by a convenience sample. The exclusion criteria were neurological or orthopedic conditions, autism, attention deficit hyperactivity disorder, or visual impairment that cannot be corrected using glasses. The study was approved by the hospital Helsinki committee (#1071-14-SMC).

### 2.2. Study Tools

The DCDQ was used in this study to gather information on the research group of children with DCD. The DCDQ [19] is a 15-item questionnaire, where parents rate the motor abilities of their child (from '1'–'does not describe my child' to '5'–'fully describes my child'), culminating in a score ranging from 15 to 75. A score in the DCDQ of up to 46 was suggested as the best cutoff score to identify children with DCD or suspect for DCD (Wilson et al., 2009).

The MABC-2 [20,21] for the age group of 3–6 years old contains 8 tasks. Of these, three tasks evaluate manual dexterity (posting coins, treading beads, and tracing a bicycle trail with a pencil), two tasks evaluate visual-motor coordination (catching a beanbag and rolling a ball into a goal), and three tasks evaluate static and dynamic balance (one-leg balance with each leg, jumping forward, and walking with raised heels). A score up to the 5th percentile is an indication of motor difficulty, a score between the 5th and 16th percentiles indicates suspicion of motor difficulty, and a score above the 16th percentile indicates normal motor function.

A portable, non-immersive VR game, designed by an occupational therapist and fitted for children with motor difficulties (Timocco, Tel Aviv, Israel), utilizes a laptop with a webcam and two soft playing balls of different colors, worn on each hand like a glove. The movement of each ball is identified by the camera in real-time, and controls the hand movements of a virtual monkey, displayed on the screen. Each ball controls the mirrored virtual hand. A game named "Falling Fruit" was chosen for this study out of a number of available games. During this game, the virtual monkey has to catch a piece of fruit dropping from the top of the screen, and place it in one of two baskets, set near the legs of the monkey. This game was chosen since it requires visual tracking of a moving target (the virtual fruit), reaching towards a moving target, and also movement to a stationary target (the virtual basket). Other games did not include all the aforementioned requirements, e.g., a game of balloon popping did not include movement towards a stationary target. The balloon popping game was therefore used only for practice, in order to get the child acquainted with the system. The computerized game records the total score (number of pieces of fruit placed in the basket—a higher score indicates higher success in the game), and the path length of each hand during the game [22,23].

Lastly, a thin pressure-measuring pad was taped to the floor. The pad consisted of 256 pressure sensors (M-flex, size 53 cm × 53 cm). The location of the COP was recorded during the trial.

### 2.3. Protocol

The parents read and signed an informed consent form, and the child agreed to participate in the study. The parents filled out the DCDQ. The MABC was administered. Following a 5-minute rest, the subject was asked to stand barefoot on the pressure pad placed on the floor, and practice for two minutes playing different games on the VR system, to get acquainted with the device. The subject then played for three minutes in a game where balloons showed on the screen and he or she had to pop the balloon. Following a short rest, the trial began, and the subject played three minutes of the falling fruit game.

### 2.4. Post Analysis

Data extracted from the VR system include the game score (how many pieces of fruit were placed in the baskets during the 3-minute trial), as well as the coordinates of the hand-held balls. The latter were used to calculate the path length in meters of each hand, according to the following formula:

$$Hand\ path\ [m] = \sum \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} \tag{1}$$

The following three COP-related measurements were calculated using a custom LabView code (V12, National Instruments, Austin, TX, USA): the total COP path length, as well as both the

Anterior-Posterior (AP) and Medio-Lateral (ML) ranges of the COP in centimeters. The COP was calculated according to the following formulas:

$$COP_X = \frac{\sum P_i \cdot X_i}{\sum P_i};\ COP_Y = \frac{\sum P_i \cdot Y_i}{\sum P_i} \tag{2}$$

where $P_i$ is the pressure measured with sensor $i$, located at $(X_i, Y_i)$. The $x$-axis represents the ML direction and the y-axis represents the AP direction.

The statistical analyses were performed using SPSS version 24. Normal distribution of the measured parameters was tested using the Shapiro–Wilk test. Since some of the variables were not normally distributed, we conducted various parametric statistical analyses. The Mann–Whitney U test was used to find between-group differences. The Spearman's rank-order correlation was used to find correlations between the MABC scores and the scores from the VR game, hand movement paths, and the aforementioned COP-related parameters in the research group. Grubb's test was used to detect outliers. The power of the findings was calculated using G*Power (version 3.0.10, Germany). For all of the statistical analyses, the significance level was set to $p < 0.05$.

## 3. Results

The personal characteristics of the subjects are presented in Table 1 for both groups, as well as the DCDQ scores of the research group. We performed the Mann–Whitney U test as a pre-analysis to test for gender differences in the results. The test was performed on all of the measured parameters between the boys and girls of the entire study population, and also separately in each group. No gender differences were found.

**Table 1.** Personal characteristics of the participants, and the Developmental Coordination Disorder Questionnaire (DCDQ) score of the research group. Quantitative data are presented as median and interquartile percentages.

| | **Research Group (N = 10)** | **Control Group (N = 20)** | ***p*** |
|---|---|---|---|
| Gender | 4 boys, 6 girls | 10 boys, 10 girls | 0.611 |
| Age (years) | (5.1–6.1) 5.7 | (4.5–5.7) 5.3 | 0.058 |
| Dominant hand | 7 right, 3 left | 19 right, 1 left | 0.162 |
| DCDQ | (30.1–40.5) 37.0 | - | - |

The game score achieved by the control group was significantly higher (approximately 22% higher) than the game score achieved by the research group (Table 2). There were statistically significant differences in the total and subcategory scores of the MABC between the research and control groups (Table 2). There were no statistically significant differences in the three COP-related parameters between the two groups (Table 2). Also, there were no statistically significant differences in the path length of each hand between the two groups, although there appeared to be a trend towards a longer path of the right hand in the control group ($p = 0.078$).

**Table 2.** Movement Assessment Battery for Children (MABC) scores, Center of Pressure (COP)-related parameters, hand path lengths and game score of the two groups, presented as median and interquartile percentages.

| | Research Group (N = 10) | Control Group (N = 20) | Z | *p* |
|---|---|---|---|---|
| **MABC parameters** | | | | |
| Total score | **0.8 (0.5–5.0)** | **(37.0–63.0) 37.0** | **−4.443** | **<0.001** |
| Manual dexterity score [%] | **(0.5–1.3) 0.5** | **(25.0–50.0) 37.0** | **−4.447** | **<0.001** |
| Visual-motor coordination score [%] | **(8.0–40.3) 31.0** | **(50.0–75.0) 75.0** | **−3.764** | **<0.001** |
| Balance score [%] | **(1.0–7.0) 5.0** | **(25.0–50.0) 37.0** | **−3.593** | **<0.001** |
| **COP parameters** | | | | |
| AP range [cm] | 4.3 (2.9–17.1) | 5.8 (3.9–8.3) | −0.453 | 0.651 |
| ML range [cm] | 10.1 (4.9–18.0) | 6.5 (3.8–8.5) | −0.906 | 0.365 |
| Path length [cm] | 118.1 (78.0–212.2) | 101.3 (84.0–139.3) | −0.728 | 0.467 |
| **Game parameters** | | | | |
| Score in game | **275.0 (157.5–297.5)** | **335.0 (226.2–522.5)** | **−2.036** | **0.042** |
| Right hand path length [m] | 20.8 (7.8–37.9) * | 39.0 (19.4–74.2) | −1.760 * | 0.078 * |
| Left hand path length [m] | 38.9 (17.5–59.5) | 47.0 (26.5–75.3) | −0.880 | 0.379 |

MABC = Movement Assessment Battery for Children; COP = Center of Pressure; AP = Anterior-Posterior; ML = Medio-Lateral * When removing an outlier from the research group, found using Grubb's test, the median and interquartile percentage of the right hand path length is 19.0 (6.1–30.1), and statistically significant between-group difference is found (Z = −2.168, *p* = 0.030).

In the research group, the COP-related parameters, the path length of the left hand, and the VR game score did not correlate with the scores of the MABC and its subcategories (Table 3). The path length of the right hand showed very strong correlation with the visual-motor coordination MABC subcategory score (Table 3, Figure 1), and strong correlations with the balance MABC subcategory score and the total MABC score (Table 3). It did not correlate, however, with the manual dexterity MABC subcategory (Table 3). The power values of the correlation between the right-hand path length and the visual-motor coordination score, balance score, and total MABC score were 99.9%, 91.3%, and 69.9%, respectively. Figure 1 depicts a scatter plot of the visual-motor coordination MABC subcategory scores in relation to the path length of the right hand in the research group. The three left-handed subjects are marked in gray. Due to the significant findings relating to the path length of the right hand, we searched for correlation (using Spearman's rank correlation test) between the path length of the right hand and the DCDQ scores, and found significant correlation with a correlation coefficient of 0.687 (*p* = 0.028).

**Table 3.** Spearman's correlations (r,p) between scores of the MABC, its subcategories and COP-related parameters, hand paths, and game score in the research group (N = 10).

| | Manual Dexterity [%] | Visual-Motor Coordination [%] | Balance [%] | Total [%] |
|---|---|---|---|---|
| AP range of COP [cm] | 0.294, 0.443 | 0.102, 0.795 | −0.128, 0.743 | −0.196, 0.614 |
| ML range of COP [cm] | 0.606, 0.084 | 0.085, 0.828 | −0.085, 0.828 | −0.088, 0.823 |
| COP path length [cm] | 0.330, 0.385 | 0.017, 0.965 | −0.238, 0.537 | −0.101, 0.795 |
| Right hand path length [cm] | 0.274, 0.443 * | **0.902, <0.001 *** | **0.769, 0.009 *** | **0.667, 0.035 *** |
| Left hand path length [cm] | −0.254, 0.480 | 0.202, 0.575 | 0.185, 0.610 | 0.071, 0.845 |
| Score in game | −0.329, 0.353 | 0.622, 0.055 | 0.551, 0.098 | 0.276, 0.441 |

MABC = Movement Assessment Battery for Children; COP = Center of Pressure; AP = Anterior-Posterior; ML = Medio-Lateral. * When removing an outlier in the right hand path length data from the research group, found using Grubb's test, the Spearman's correlations (r,p) are corrected for manual dexterity (0.158, 0.648), visual-motor coordination (0.865, 0.003), balance (0.732, 0.025), and the total score (0.778, 0.014).

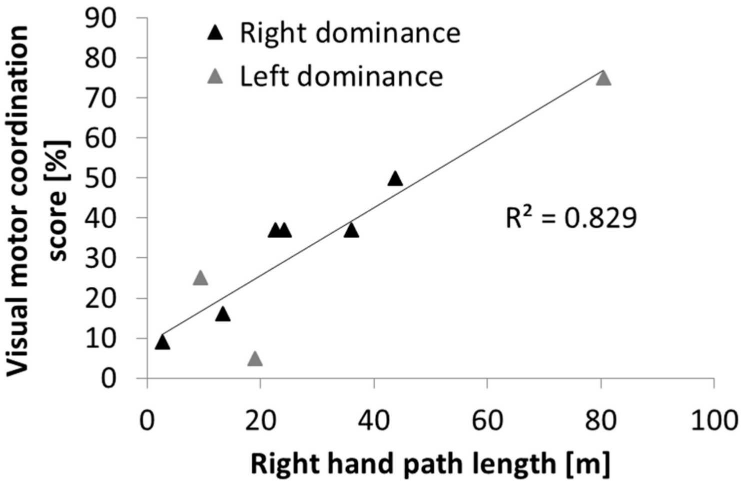

**Figure 1.** The visual-motor coordination Movement Assessment Battery for Children (MABC) subcategory scores as a function of the recorded right-hand path length while playing a virtual reality game for activation of the upper limbs. Data are presented for children with Developmental Coordination Disorder (DCD). Note: when removing an outlier in the right-hand path length data from this group, found using Grubb's test, the $R^2 = 0.717$.

## 4. Discussion

In this study, we compared the performance in a VR game between TD children and children with DCD, and explored the correlations between the performance of children with DCD in the game and the MABC. Our main findings were that the VR game score was able to discriminate between TD children and children with DCD. Also, in the DCD group, the hand path length strongly correlated with the visual-motor coordination MABC subcategory score and with the balance MABC subcategory score, as well as with the total MABC score. This is the first study that presents such findings in the young population of 5-year old children, and our results place the foundation for future validation of this tool as a measuring instrument for children with DCD.

The similarity in hand path lengths recorded while playing the VR game between TD children and children with DCD was also noted in the older population of TD children and children with DCD playing VR games [17]. The authors reported faster hand movement for the TD children. This might explain the higher score achievements of TD children in our study, despite the similar hand path length. Another explanation might be the degree of accuracy required to hit the targets, so that while both groups managed to reach the proximity of the targets, the control group was more adept in accurate localization of the end point, and therefore better scores were achieved.

The similarity in COP movement pattern between children with DCD and TD children indicates that both groups incorporated similar postural maneuvers while playing the game. This finding suggests that a pressure sensing pad may not be an appropriate tool to discriminate between TD children and children with DCD, while playing a simple VR game that does not require lower limb movement. This finding is surprising since a previous study that compared 64 children with DCD and 71 TD 10-year-old children reported statistically significant differences in the COP path while the subjects stood quietly with their eyes open [24]. These differences, however, were not found in this study, possibly due to the different cognitive functions required while standing and while playing a VR game, which results in different mechanisms of balance control being used.

In the DCD group, there were no statistically significant correlations between the COP parameters and the MABC scores. We expected mild correlation with the balance subcategory, as COP is usually associated with balance control. However, the chosen gaming activity was not challenging in terms of balance perturbation, as opposed to the balance challenge introduced during the MABC test. So, we surmise two important notes: firstly, the COP data collected during upper limb VR gaming are irrelevant for the evaluation of DCD; secondly, the upper limb VR game, chosen for this study, produces minimal movements of the COP and may therefore be considered safe (i.e., bearing negligible risk of falling) for children with balance impairments.

In the DCD group, the right-hand path length strongly correlated with the visual-motor coordination MABC subcategory score (r = 0.902, $p < 0.001$). This finding points to a possible added value of collecting kinematics data from upper limb VR gaming, as they might be of value in a preliminary evaluation of visual-motor coordination. The VR task presented to the children in this study was more demanding, in terms of required accuracy for success and duration of the task, compared with the short tasks of catching a beanbag and rolling a ball towards a target in the MABC. It might therefore prove to be a more accurate tool in determining the visual-motor coordination capabilities of the child compared to the MABC. We believe that this could be a more reliable tool since the 3-minute long task provides the child with a large number of virtual tasks during the game, while the MABC introduces only two tasks that can be successfully completed by luck.

One of the limitations of this study is the small sample size. The technical problems experienced were also limiting, e.g., sometimes the camera did not detect the ball, so segments of the hand path were lost. The total time of the fragments of missing data, however, did not exceed 10 s during a 3-minute game. We therefore believe that the effects of these technical issues on our results are negligible. Also, we did not rate the satisfaction of the children from the VR game. Some might not have found it enjoyable. Lastly, the low resolution of the pressure mat might have caused the differences in the COP data between the two groups to become insignificant.

In conclusion, our results point to the possibility of utilizing a simple non-immersive VR game for preliminary distinction between TD children and children with DCD, by using the immediate game score. Furthermore, investigation of hand path data may reflect upon specific impairments of the child, mainly in visual-motor coordination. Due to the promising results demonstrated in this small sample-sized study, a thorough validation of the VR instrument is warranted, as a measuring instrument for children with DCD.

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