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Original article (short paper)

Value of pre-cue information for motor tasks performed by children with developmental coordination disorder (DCD)

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Abstract—People commonly use pre-cue information to advance and reduce the information processing time required for a motor task (e.g., motor planning). However, children with developmental coordination disorder (DCD) exhibit difficulties performing pre-cued goal-directed tasks. The purpose of the present study was to investigate the use of valid, neutral, and invalid pre-cue information for a goal-directed task. The participants were 11 children with DCD (mean age = 7.94 yrs.) and 11 typically developed (TD) age- and gender-matched children. The children with DCD exhibited delayed motor planning (e.g., reaction time) under the invalid condition compared to that of the TD children. The children with DCD used atypical strategies for motor execution and depended more on online corrections (e.g., increased deceleration time and movement units) to reach the target. These results suggest that children with DCD have difficulties handling unpredictable situations and that the use of atypical motor execution strategies did not affect movement time.

Keywords: pre-cue, developmental coordination disorders, reaction time, motor planning

Introduction

People use external cues to perform many motor actions. The use of pre-external cues, or pre-cues, consists of obtaining information available in the environment to advance particular neural motor planning processes for goal-directed actions[1]. Pre-cue information about a target location enables the performer to pre-program the direction parameters and the extent of motor actions before stimulus presentation[2]. Using pre-cue information in preparation to perform a motor action reduces the demand for information processing during motor planning [e.g., reaction time (RT)], motor execution [e.g., movement time (MT)], and online corrections because using good available pre-cue information can make the motor responses less dependent on external feedback and consequently, enable the central nervous system to process new information[3].

Woodworth[4] published an extensive analysis and review of human-produced targeted movements. He proposed a two-component model consisting of an initial impulse phase and an online control phase. The first phase was determined to be under central control and responsible for moving a limb to the endpoint region. The second phase was controlled by feedback for online corrections. This second phase is characterized by discontinuities in movement trajectory. The first phase involves movement acceleration toward the movement endpoint, whereas the second phase represents a deceleration phase required for roaming near the movement endpoint[5]. Deceleration time (DT) increases according to the number of movement corrections required to reach the target. In addition, changes from movement deceleration to acceleration and vice versa occur based on the number of "movement units" (MU) corresponding to the number of required corrections.

Studies that used the pre-cue paradigm have shown that children[3] and adults[6] can pre-program actions in advance to improve motor responses. Van Dellen and Geuze[3] suggested that older children pre-program movement better than younger children. However, previous studies suggested that the benefits of pre-programming actions do not differ with age[6,7]. The differences in these findings may not be developmentally related because these studies showed that very young children (e.g., 6-years-old) can benefit from motor response pre-programming and improvement among older children was small compared to that among younger children[6]. Another explanation for the differences in the findings of pre-cue paradigm studies is that the use of pre-cue information for motor responses is task-dependent[2]. Indeed, it was demonstrated that RTs of children and adults increase as a function of the complexity of the pre-cue condition[6]. The pre-cue condition increases in complexity as the amount of information available and the number of programming or re-programming steps in the motor response increase. For example, a valid pre-cue condition indicates that adequate information required for the motor response is available and is less complex than an invalid pre-cue condition in which inadequate information about the required motor response is available, leading the performer to re-program the motor response[1,2,8].

Despite the observation that the pre-cue information condition plays an important role in almost all motor actions, few studies have investigated how children with developmental coordination disorder (DCD) respond in these situations. Children with DCD have motor and learning difficulties, leading to impaired motor task performance, such as walking, jumping, running, grasping, throwing, and daily self-care activities[9,10]. These motor coordination difficulties are typically associated with psychological and behavioral factors, such as stress, anxiety, depression[11], poor academic scores, self-esteem[12] and physical fitness[13]. Although the cause of DCD is unknown, strong evidence indicates that children with DCD need more time to prepare and execute motor actions compared to their typically developing (TD) peers[14-18].

To investigate the use of pre-cue information, Mandich, Buckolz, and Polatajko[19] compared performance on a go/no-go task in response to a stimulus in 7–12-year-old children with DCD and TD children. The stimulus consisted of green- or red-filled circles, and the participants were asked to press a button on a keyboard in response to the appearance of green, but not red, circles. The pre-cue information informed (valid condition), did not inform (neutral condition), or incorrectly informed (invalid condition) where the stimulus would appear. The results showed that children with DCD exhibited slower RT and MT than those of TD children under all pre-cue conditions. The children with DCD also exhibited slower MT under the invalid condition than under the valid condition and performed more response inhibition errors (24% of attempts) than those of children with TD (11% of attempts) when the stimulus was the red circle. Such considerations are important based on evidence that children with DCD are slower than their peers at initiating a motor action and that these children have even greater difficulty handling unpredictability, as represented by their difficulty with response inhibition.

Mon-Williams[20] reported comparable RT and MT results. Those authors investigated whether children with DCD and TD children can use information in advance to pre-program motor actions for a block-reaching task. Two blocks were arranged on the right and left sides of the child. Pre-cue information informed the children which block should be targeted and lifted (complete information) or only informed the children the side of the block that should be targeted and lifted (partial information). The results showed that children with DCD exhibited slower RT and MT than those of TD children. Furthermore, children with DCD became confused and disregarded the information that was available under the partial information condition. In addition, MT was unaffected by the pre-cue information. Previous studies have shown that children with DCD exhibit slower RT and MT than those of TD children, regardless of the use of complete or partial pre-cue information[2,21].

Slowness can be a disadvantage and even a problem for children with DCD given that the control of velocity is a very important variable to accomplish daily motor tasks and, even more importantly, perform highly skilled tasks[20]. For example, if children with DCD do not move sufficiently rapidly while participating in court sports, they cannot play at a level similar to that of TD children. Children with DCD occasionally attempt to move as rapidly as TD children (similar MT) without considering the quality of the performance or without attending to task demands. In such cases, children with DCD are less precise and make more errors on goal-directed tasks than the TD children[22]. It was reported that children with DCD exhibit less recognition of and adaptation to task demands[20]. These deficiencies are the primary reason why understanding the mechanisms that support motor skill performance has become very important, particularly for those who exhibit motor difficulties. Thus, the primary objective of this study was to investigate and discuss the use of pre-cue information for a goal-directed task that requires a high level of endpoint precision under three conditions (valid, neutral, and invalid) by children with DCD and TD children. The hypothesis was that children with DCD program motor responses were slower than that of TD children but children with DCD exhibit similar MTs to compensate for this lack of adjustment programming the motor response.

Method

Participants

A total of 126 children from a public school were screened using the Movement Assessment Battery for Children (M-ABC)[23]. The M-ABC is a validated assessment battery that requires a child to perform a series of motor tasks in a very specific way to objectively measure motor impairment. Eleven participants (three males and eight females) were identified to suffer from DCD, as they scored ≤5th percentile on the M-ABC and <5th percentile on the Manual Dexterity component. Based on these results, these children were selected to participate in the experimental phase of the present study [DCD group mean age = 7.94 year, standard deviation (SD) = 0.37]. Eleven TD children were selected randomly from 50 children who scored >30th percentile on the M-ABC and were age- and gender-matched with the DCD group (TD group mean age = 7.97 years, SD = 0.31). The parents of these children provided consent for their participation in this study according to the University Ethics Committee (protocol 3260).

Materials and Experimental Task

The participants sat on a chair that was adjusted for their height in front of a table with a tablet (Intuos2, 12 × 18” Wacom Co., Ltd., Saitama, Japan) and a 17” LCD monitor placed behind the tablet 40 cm in front of the participant (Fig. 1a). The participants were asked to place the stylus on the initial mark (0.7 cm side of a green square) located on the lower portion of the tablet screen and to use the stylus to reach the target on the right or left side of the initial mark after an imperative stimulus appeared on the screen. The initial mark and the target mark projected on the monitor were drawn in the corresponding location on the tablet in a 1:1 ratio (Fig. 1b). The tablet was connected to a personal computer, and data were acquired using MovAlyzer software (NeuroScript LLC., Tempe, AZ, USA).

After the stylus was positioned properly on the tablet, the pre-cue (arrow pointed to the left or right or a plus sign for the neutral condition) was presented on the monitor for 800 ms and then disappeared. This pre-cue was shown within a square (3.6 cm side) positioned 14 cm above the initial mark on the monitor (Fig. 1c). After the pre-cue disappeared, an imperative stimulus (target that should be targeted using the stylus) was presented on the monitor after a randomized period of 1,200–1,800 ms. The target was a black-filled circle (0.5 cm diameter) inside a red square (1 cm side) positioned 16 cm to the right or left of the initial mark at a horizontal angle of 49°. After receiving the pre-cue information and the imperative stimulus, the participant was asked at the tablet, not the monitor, to reach for the target on the tablet. The trajectory of the stylus remained visible on the screen until the start of the next trial, so the participants received immediate feedback concerning their action. In addition, the target remained on the monitor until the participants accomplished the task by stopping the stylus at the target on the tablet.

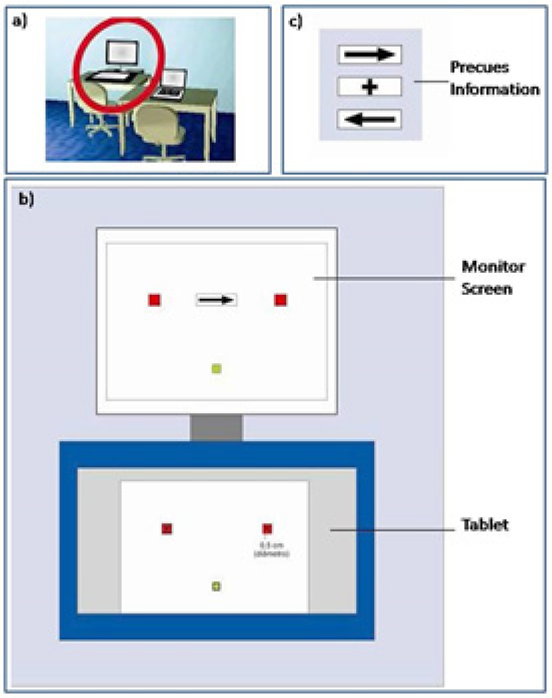

Figure 1. (a) Illustration of the experimental setup. Highlight: Table containing the tablet and monitor; (b) illustration of the experimental marks and targets on the monitor and tablet; and (c) types of pre-cue information (arrows), indicating the side where the imperative stimulus (red square) or not (plus sign) appeared.

Procedures

The chair was adjusted for the height of the participant. The participant was asked to write their name on the tablet to become familiarized with the equipment, and then the experimenter provided instructions about the experimental task. The instructions were to follow the imperative stimulus to reach the target as quickly as possible without lifting the stylus from the tablet surface. The participants did not receive information about the pre-cue information condition. A valid pre-cue condition was one in which the pre-cue corresponded to the imperative stimulus. An invalid pre-cue condition was one in which the pre-cue did not correspond to the imperative stimulus. A neutral pre-cue condition did not indicate the side in which the target would appear.

Each participant in each group began the experiment by completing 24 valid pre-cue trials (12 for each target location) for habituating the participants to always expect valid pre-cue information to advance the motor program under both the valid and invalid conditions. Then, the trials were completed in two blocks: (i) 10 trials under the neutral condition and (ii) 60 trials under the valid/invalid conditions. The order of the neutral and valid/invalid conditions was counterbalanced among the subjects in each group. The neutral trials were performed as a separate block because they did not affect the pre-cue valid/invalid paradigm, because no target information was provided in advance. The valid/invalid conditions began with 10 consecutive valid trials followed by 50 randomized trials (40 valid and 10 invalid). The right and left positions of the target were presented randomly during each trial block.

Data Reduction and Dependent Variables

The data analysis was performed using MatLab 7.0 software (Math Works, Natick, MA, USA). All 10 trials from the neutral condition block, the first 10 valid trials, and all 10 invalid trials from the valid/invalid condition block were used for the data analysis. The first 10 valid trials from the valid/invalid condition block were used for the analysis because they were unaffected by the expectation of the appearance of an invalid pre-cue. Trials were excluded based on the following criteria: (1) RT < 200 ms during anticipation and/or >1,500 ms during inattention or distraction; (2) MT > 4,000 ms; and (3) failure to accomplish the task (reaching the target with the stylus and maintaining it on the target for at least 500 ms). The data for the X- and Y-positions (Cartesian) of the stylus trajectory over time were captured at a frequency of 100 Hz.

The RT of each trial analyzed was calculated as the time interval between the moment the imperative stimulus appeared to the first moment the stylus was displaced on the tablet. This dependent variable provides information about internal processes occurring during motor preparation. The MT of each trial analyzed was calculated as the time interval between the first moment the stylus was displaced to the final moment of stylus displacement, i.e., MT was the time movement that was performed by the participant to accomplish the task. DT of each trial analyzed was calculated as the time interval between the moment the participant reached the maximum peak velocity of stylus displacement to the final moment of stylus displacement. A smaller DT indicates that fewer adjustments were necessary to accomplish the task. The MU was calculated as the number of peak velocities between the two minimal velocities, whose differences were >1 cm/s[24]. The number of MUs indicates the movement flow conducted to reach the target; fewer MUs indicate more flowing movement and less online control dependency.

Statistical Analysis

The statistical analysis was performed using Statistica ver. 7.0 software (Dell Statistica, Tulsa, OK, USA). Four 2 (groups: DCD and TD) × 3 (conditions: neutral, valid, and invalid) analysis of variance (ANOVA) were performed for RT, MT, DT, and MU. The Epilon Huynh-Feldt correction was applied for F-value adjustments. Significant effects were investigated using Tukey's HSD post-hoc test. A p-value < 0.05 was considered statistically significant.

Results

Reaction Time

The results showed a significant effect of group and condition [$F(1,20) = 9.99$, $p < 0.01$, partial $\eta^2 = 0.33$ and $F(2,40) = 18.731$, $p = < 0.01$, partial $\eta^2 = 0.48$, respectively] but no significant interaction effect. In general, RT of the children with DCD was significantly longer under the invalid pre-cue condition than that of the TD children ($p = 0.03$). These results indicate that children with DCD take more time than TD children to plan movement when invalid information is presented in advance (Fig. 2). RT under the valid pre-cue condition was significantly shorter than that under the neutral pre-cue condition for all children ($p < 0.01$), and RT under the neutral pre-cue condition was significantly shorter than that under the invalid condition ($p = 0.01$).

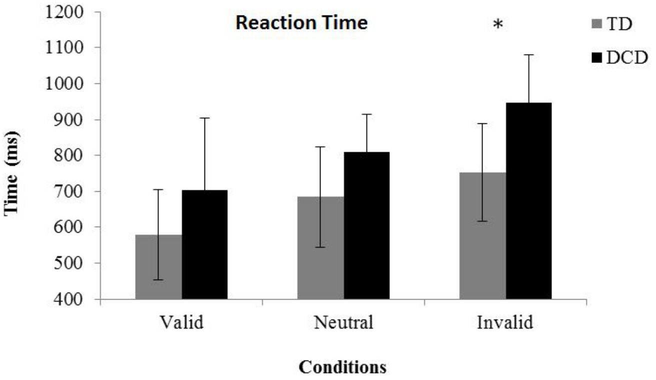

Figure 2. Reaction time (ms) of children with developmental coordination disorder (DCD) and TD children under the valid, neutral, and invalid pre-cue information conditions.

Movement Time

ANOVA of the MT results revealed no significant group, condition, or group × condition interaction effect ($F(1, 20) = 2.64$, $p = 0.120$, partial $\eta^2 = 0.11$; $F(1, 20) = 0.44$, $p = 0.643$, partial $\eta^2 = 0.02$; and $F(2, 40) = 0.\ 42$, $p = 0.657$, partial $\eta^2 = 0.02$, respectively). Figure 3 shows the mean MTs for both groups.

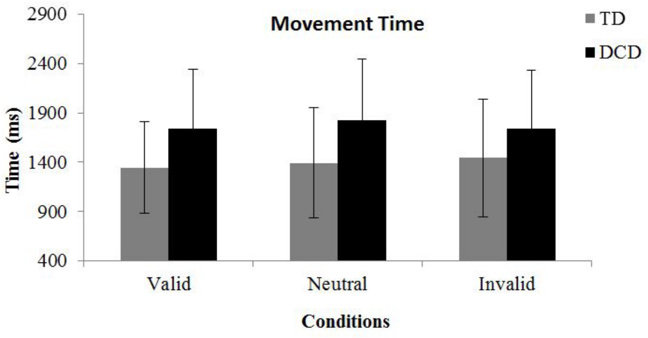

Figure 3. Movement time (ms) of children with developmental coordination disorder (DCD) and typically developed (TD) children under the valid, neutral, and invalid pre-cue information conditions.

Deceleration Time

The ANOVA results indicated no significant group, condition, or group × condition interaction effect ($F(1,20) = 3.32$, $p = 0.08$, partial $\eta^2 = 0.14$; $F(1,20) = 0.02$, $p = 0.97$, partial $\eta^2 = 0.00$; and $F(2,40) = 0.02$, $p = 0.97$, partial $\eta^2 = 0.00$, respectively). However, Figure 4 shows a tendency for the DCD children to spend more time decelerating ($p = 0.08$), indicating that children with DCD adjusted more frequently to reach the target.

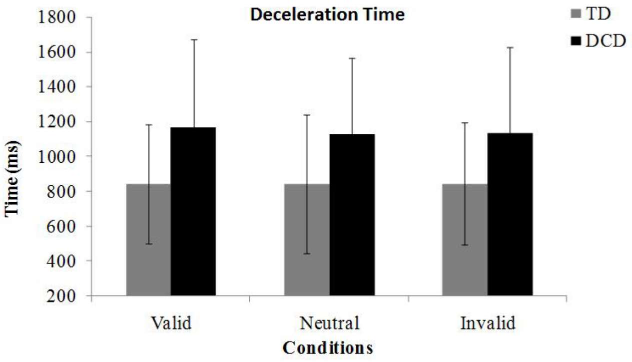

Figure 4. Deceleration time (ms) of children with developmental coordination disorder (DCD) and typically developed (TD) children under the valid, neutral, and invalid pre-cue information conditions.

Movement Units

ANOVA of the MU results indicated a significant group effect [$F(1,20) = 4.44$ $p < 0.05$, partial $\eta^2 = 0.18$] but no significant condition or group × condition interaction effect [$F(1,20) = 0.12$, $p = 0.87$, partial $\eta^2 = 0.00$ and $F(2,40) = 0.95$, $p = 0.39$, partial $\eta^2 = 0.04$, respectively]. These results show that TD children required fewer MUs to reach the target than that of children with DCD ($p = 0.04$).

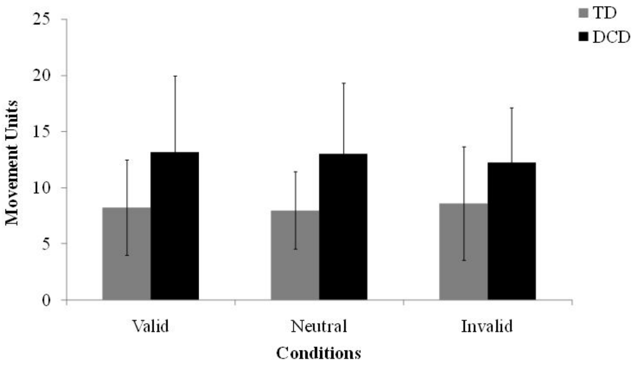

Figure 5. Movement units of children with developmental coordination disorder (DCD) and typically developed (TD) children under the valid, neutral, and invalid pre-cue information conditions.

Discussion

Children with DCD are slower than their TD peers at initiating and executing motor responses[14-17]. However, few studies have explored the behavior of children with DCD on the experimental pre-cue paradigm[1,8]. The present study investigated how children with DCD perform actions under valid, neutral, and invalid pre-cue information conditions. The results show that children with DCD exhibited increasing deficiencies as a function of condition complexity from the valid to the invalid pre-cue conditions. Children with DCD performed more poorly under the invalid condition but performed similarly under the valid condition compared with the TD children. These results are in accordance with those of Mandich[19], who reported that children with DCD have many difficulties handling invalid pre-cue information compared with valid or neutral information. It appears that children with DCD require a longer time and make more mistakes during a motor action when changing from a pre-programmed motor plan to a reorganized motor response.

Previous studies verified that children with DCD take advantage of valid pre-cue information to pre-program a motor plan for goal-directed actions. In both studies, although children with DCD were able to use valid pre-cue information, they remained slower at initiating a motor response than their peers[2,20]. These results are not in accordance with the results obtained in the present study, in which children with DCD showed a similar RT to that of TD children when initiating a motor response under the valid pre-cue condition. This contradictory result for children with DCD under the valid pre-cue condition may be due to differences in task demands compared to those seen previously[2,20]. In the present study, although the RT results were similar for both groups under the valid pre-cue condition, the high level of endpoint precision demand may have affected the two groups differently. In other words, children with DCD appear to use a different strategy than that of TD children during motor preparation. In particular, TD children processed most spatial and temporal information before initiating the task, whereas children with DCD appeared to start the movement relatively earlier than children with TD despite having processed less information and relied more heavily on online corrections, such as final adjustments[2]. Consistent poor motor execution performance was exhibited by children with DCD in the present and previous studies[2,20-22], supporting this concept and confirming the dependency of task demand on pre-cue motor actions.

No differences in motor execution results (e.g., MT, DT, and MUs) were observed in the pre-cue information conditions between the groups. These results are not completely in accordance with those of Van Dellen and Geuze[3] who suggested that the availability of valid pre-cue information accelerates motor planning (e.g., RT) and motor execution. In the present study, although RTs were significantly faster under the valid and neutral pre-cue conditions than under the invalid pre-cue condition, no differences in motor execution were observed between the different conditions in either group. These results are in accordance with the results reported by Mon-Williams[20].

In summary, three relevant findings were obtained from the present study: (i) the results involving motor planning (e.g., RT) and motor execution (e.g., MT, DT, and MUs) in a pre-cue experimental paradigm[1,8] were highly dependent on the task demand; (ii) children with DCD exhibited many difficulties with handling unpredictable situations, as demonstrated under the invalid pre-cue condition in the present and previous study[19]; and (iii) the performance of children with DCD on the task employed in the present study suggests that valid and neutral pre-cue information conditions may serve as a good alternative for intervention to improve the level of performance of children with DCD.

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