Perceived Hole Size, Performance, and Body Movement During Putting in Children With and Without Probable Developmental Coordination Disorder

Fu-Chen Chen and Sheng-Kuang Wu

The purpose of this study was to examine the relationships between perceived hole size (perception), performance, and body movement (action) in golf putting for children with probable developmental coordination disorder (DCD) and typically developing children (TDC). Forty-eight children (24 probable DCD, 24 TDC) performed putting in easy and hard conditions. Body movement was measured during putting, performance was measured as the distance between ball and hole, and perceived hole size was recorded using a Microsoft Paint drawing exercise 1 m away from the hole. The present results revealed that perceived hole size was positively related to putting performance, body movement was negatively associated with putting performance, and that there were negative correlations between body movement and perceived hole size. While children with probable DCD tended to perceive the hole as smaller, perform worse, and show more body movement, TDC exhibited the opposite. These findings help characterize the relationships between perception, performance, and action in children with probable DCD and TDC during golf putting.

According to the DSM-IV-TR (American Psychiatric Association, 2000), developmental coordination disorder (DCD) affects a section of the population whose level of competence in movement skills is significantly below the norm and who do not have a medical condition or any symptoms of pervasive developmental disorder. In addition, movement difficulties must interfere significantly with activities of daily living or academic activities that require perceptual motor coordination. DCD is prevalent in approximately 6% of children aged 5–11 years, indicating that it is a significant disorder (APA, 2000). Children with DCD experience difficulties in a wide spectrum of activities, including both fine and gross movements such as tying shoelaces, handwriting, using scissors, catching a ball, running, jumping, hopping, and riding a bicycle. A wealth of research has demonstrated that physical activities and movements are difficult for children with DCD, such that they are less likely...
to be physically active or to participate in free play and organized activities with their peers. Their movement difficulties not only impact on their physical activity levels and sport participation but also affect cardiopulmonary fitness (Wu et al., 2010) and health (Cairney et al., 2007). Unfortunately, the etiology of DCD has remained a mystery, and most children with DCD continue to manifest movement difficulties into adulthood (Losse et al., 1991).

Some studies have sought to identify the differences between children with DCD and typically developing children (TDC) in pure perceptual deficits such as kinesthesis (Piek & Coleman-Carman, 1995), visuospatial perception (Schoemaker et al., 2001), and perceived action possibilities (Johnson & Wade, 2007; 2009), suggesting a flaw in the perceptual system of children with DCD. Other studies have focused on investigating pure movement difficulties in actions such as standing balance (Geuze, 2003; Tsai et al., 2008), walking pattern (Deconinck et al., 2006), and ball catching (Utley et al., 2007), demonstrating a weakness in body movement control in DCD children. In fact, body movement control has been shown to influence perception and further affect the performance of perceptual motor tasks (Chen et al., 2011; Stoffregen et al., 2006; Stoffregen et al., 2007); yet, only a few studies have specifically examined how body movement relates to perception and performance while engaging in perceptual motor tasks.

One such example is a study by Whitall et al. (2006), who asked children with and without DCD to clap and march to an auditory beat and examined the relationship between perceptual and motor processes, also known as perception-action coupling. Later, Whitall et al. (2008) used a finger-tapping task in a study where children were required to tap fingers simultaneously with an auditory signal. These studies demonstrated that compared with TDC, children with DCD were less stable and less able to control the coordination pattern for auditory-motor coupling in these perceptual motor tasks. Nevertheless, since physical activity was not measured, how limb movement relates to auditory perception remains unclear for children with DCD. Chen et al. (2011) employed a postural and suprapostural dual-task paradigm in their study, where children with DCD (who were ruled out as having attention deficit-hyperactivity disorder, ADHD) and TDC were asked to perform a signal-detection task while maintaining a stance at two levels of difficulties. While there was reduced postural activity in TDC, who were also able to detect smaller variations in visual target patterns and performed better with signal detection, children with DCD were found to have increased postural activity and exhibited worse performance. Since none of the participants had attention problems, a possible relation between performance, perception, and action was suggested: Postural activity was reduced to better perceive visual information, in turn facilitating performance in the signal-detection task. This relation is commonly found in daily activities; for example, reading is only successful when the reader is able to control the head and gaze to clearly view the text. Based on the action-modulated perception account, an individual’s perception of the surrounding environment is determined by their capacity to perform effectively in the environment (Witt, 2011). Recently, Witt and Dorsch (2009) provided empirical evidence that football players who perform well perceived the goalposts to be farther apart and the crossbar to be lower. Similarly, golfers who performed better on the day estimated the hole to be bigger than those who performed worse. Accordingly, the poor motor coordination
ability of children with DCD should hypothetically lead to an underestimation of target size. However, in Chen et al.’s study (2011), the perceived length of visual targets was not measured, leaving some doubts about the details of the perception-action link in children with DCD.

We are not aware of any existing research on the association between perceptual estimation, performance, and body movement in children with and without DCD. The present study thus sought to determine whether perceptual estimation, performance, and body movement are associated with each other in children with probable DCD while they are engaged in a perceptual motor task (golf putting). This task was chosen because it is an activity that profoundly involves precision, postural control, coordination, and finely tuned movements (Weinberg & Genucci, 1980), where any interference with the control of the putting motion might have a major effect on putting performance. We compared perceived hole size, performance, and body movement in children with probable DCD and TDC while executing golf putting at two putting distances. We hypothesized: (1) that children with probable DCD would perceive hole size as smaller than TDC; (2) that the putting performance of children with probable DCD would be lower than that of TDC; (3) that perceived hole size would be positively related to putting performance in both groups; (4) that, averaged over children with DCD and TDC, body movement would be negatively associated with putting performance; and (5) that there are negative correlations between body movement and perceived hole size, demonstrating the characteristics of the perception-action link in TDC and children with probable DCD.

**Method**

**Participants**

The study procedure was approved by the National Cheng Kung University Research Ethics Committee for Human Behavioral Science. All participants and their parents provided written informed consent. Two hundred and eighty-nine children from Chi-Kuang Elementary School (Hsinchu County, Taiwan) were screened by an experienced group of evaluators with a background in pediatric physical therapy, using the second edition of the Movement Assessment Battery for Children (MABC-2; Henderson, Sugden, & Barnett, 2007). Forty-eight (24 boys, 24 girls) children aged 11–12 were recruited in this experiment, including 24 (12 boys, 12 girls) children with probable DCD and 24 (12 boys, 12 girls) TDC. All participants were inexperienced golfers. There were no significant differences between the probable DCD and the TDC groups in age, body height, body weight, body mass index (BMI), and intellectual quotient (IQ; Table 1).

Children were recognized as exhibiting probable DCD based on their performance on the MABC-2, the most common test used to identify motor coordination difficulties in children. Interrater reliability of the MABC-2 ranges from 0.92 to 1 (Henderson, Sugden, & Barnett, 2007). The convergent validity between the McCarren Assessment of Neuromuscular Development (MAND) and the MABC-2 has been found to be 0.67 (Cronin, 2010). For the age range of 11–16 years, there are eight subtests covering the domains of manual dexterity, aiming and catching, and balance. The subtests are turning pegs, threading nuts into bolts, drawing a trail,
catching a ball, throwing a ball at a wall target, balancing on two boards, walking backward, and zigzag hopping. Adding the scores from each of the three domains gives the total score. A higher total score represents better motor coordination performance and vice versa. Probable DCD was defined as a total score of 56 or lower (below the 5th percentile), while children were defined as TDC with total scores at or above 67 (above the 15th percentile), as specified in the test manual. The performance scores of the probable DCD group in the MABC-2 test ranged from the 0.5th to the 5th percentile, and those of the TDC group ranged from the 25th to the 95th percentile (Table 1). The standard scores of the probable DCD group were significantly lower than those of the TDC group for manual dexterity ($t = 10.92, p < .05$), aiming and catching ($t = 15.83, p < .05$), and balance ($t = 12.79, p < .05$), as was the total score ($t = 21.98, p < .05$).

The diagnosis of ADHD was excluded based on scores on the ADHD rating scale (ADHD-RS; DuPaul, Power, Anastopoulos, & Reid, 1998). In ADHD-RS, there are nine test items regarding the frequency of ADHD symptoms in each of the inattention and hyperactivity/impulsivity domains. Each test item is rated as always/very often, often, somewhat, or rarely/never. Inattention subtype ADHD is determined when more than 6 items in the inattention domain are rated as always/very often or often. Hyperactivity/impulsivity subtype ADHD is determined when more than six items in the hyperactivity/impulsivity domain are rated as always/very often or often. There were no group differences in total scores on the ADHD-RS and none of the participants met the criteria for being diagnosed with ADHD (Table 1).

### Apparatus

**AMTI Force Plate.** Data about center-of-pressure (COP) excursions were recorded in real time while participants executed golf putting on an AMTI Accusway force plate (Advanced Mechanical Technology, Inc., Newton, MA, USA) with
a sampling rate of 100 Hz. Data were recorded from the “ready, go” signal until the putter made contact with the ball. The force plate was connected to a personal laptop computer, which collected and stored data for subsequent analysis.

**Putting Platform.** A 2.44-m (8 feet) long, 0.91-m (3 feet) wide, and 5.08-cm (2 inches) tall putting platform, covered with a putting carpet, was custom-made to simulate a golf green (Figure 1). The coefficient of friction of the carpet was 0.069. The height of the platform was identical to that of the AMTI force plate, such that the force plate could be situated adjacent to the platform and participants could stand on the force plate while putting a ball that was set on the platform. The target hole was 10.80 cm (4.25 inches) in diameter, which is equal to the standard size of a golf hole.

The present study was completed in a quiet room in the student recreation center at a children’s school. First, each participant was provided with a putter (USKG-508; length: 82 cm [32.28 inches]; weight: 500 g [1.10 lbs]), instructed on how to putt, and given 5 mins of practice. Participants were requested to stand on the force plate and putt a golf ball toward a hole as accurately as possible. Once they set the putter right behind the golf ball, appeared to stand still, and were looking at the ball, the instruction “ready, go” was given by an experimenter, and participants began to execute the putting motion at their own pace. There were two experimental conditions: easy and hard. In the easy condition, the golf ball was set 0.76 m (2.5 feet) away from the hole, and in the hard condition, the ball was set 1.98 m (6.5 feet) away.

Participants were permitted five practice putts in each condition. They then performed 20 trials of putting, 10 in each condition. The force plate was calibrated to prevent any systematic bias in the measurement of contact force and ground reaction force as the putter made contact with the ball.

![Figure 1](image)

*Figure 1* — Putting platform with two X marks on the platform. The distances from each mark to the hole are 0.91 m (2.5 feet) and 6.44 m (6.5 feet).
before each trial. Trials for each condition were performed in blocks. The order of the presentation of each condition was randomized and counterbalanced across participants. A trial was considered complete when the putted ball came to a stop. A researcher measured the distance between the ball and the center of the hole using a tape measure to analyze putting performance, with a shorter distance indicating better putting performance. Successful putts were recorded as 0 cm. This method felt to quantify putting accuracy more precisely than merely recording the fraction of successful putts (Cooke, Kavussanu, McIntyre, & Ring, 2010; Wilson, Smith, & Holmes, 2007). After each putt, the ball was placed back at the starting point for the next attempt.

Finally, participants were asked to sit in front of a 15-in laptop, positioned 1 m away from the hole and, using the eclipse tool in Microsoft Paint, to draw a black circle that was identical to the physical size of the hole while they were able to view the actual hole. Participants were encouraged to redraw and to spend as much time as they needed to estimate the size of the hole and draw.

**Statistical Analysis**

The dependent variables in our study were, perceived hole size, putting performance, and body movement. Perceived hole size was defined as the hole diameter in the drawing. Putting performance was defined as the inverse distance between a stopped ball and the hole. Body movement was defined operationally as the standard deviation (SD) of the COP excursion, a method employed in earlier research (Chen, Tsai, Stoffregen, & Wade, 2011; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006). Body movement was analyzed separately for both the anterior/posterior (AP) and mediolateral (ML) axes, which were defined relative to the force plate. An independent $t$ test was used to compare perceived hole size between groups. Separate Group (2: probable DCD vs. TDC) × Putting Condition (2: easy vs. hard) repeated measures analyses of variance (ANOVAs) were conducted with the between-subject variable of Group, the within-subject variable of Putting Condition, and the dependent variables of putting performance and body movement. Since Group × Putting Condition interactions were found, several $t$ tests were conducted to test the group differences in each condition, as well as to test how each group changed body movement and putting performance between conditions. The associations between perceived size of an action-related target and sport performance have frequently been reported in previous studies (Witt & Dorsch, 2009, Witt & Proffitt, 2005, Witt, Linkenauger, Bakdash, & Proffitt, 2008). Thus, the analysis of Pearson product-moment correlation was performed to determine the correlations between perceived hole size and putting performance. In addition, Pearson product-moment correlations between body movement and putting performance were conducted to test whether body movement was related to putting performance in both groups. Last, we calculated Pearson product-moment correlation coefficients to determine the magnitude of the correlations between body movement and perceived hole size summing over children with probable DCD and TDC. All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS Inc. Version 15.0, Chicago, IL, USA). Hypothesis tests were considered significant at the $p < .05$ level.
Results

Perceived Hole Size

The mean (SD) perceived hole size was 8.01 cm (0.47) for the probable DCD group, and 9.28 cm (0.64) for the TDC group. The main effect of Group was significant, $t(1, 46) = 7.80, p < .05$, revealing that the perceived hole size was larger for the TDC group than for the probable DCD group.

Putting Performance

The main effect of Group was significant, $F(1, 46) = 188.02, p < .05$, showing that children with probable DCD performed worse at putting than their typically developing peers. The effect of Putting Condition was also significant, $F(1, 46) = 333.49, p < .05$, suggesting that the manipulation of putting difficulty was effective. Unsurprisingly, the hard condition was more difficult than the easy condition for both groups. Moreover, the results showed a significant interaction effect between Group and Putting Condition for putting performance, $F(1, 46) = 21.17, p < .05$. The t tests further revealed that children with probable DCD had significantly lower putting performance than the TDC group in the easy condition, $t(1, 46) = –3.2, p < .05$, and in the hard condition, $t(1, 46) = –4.28, p < .05$. In addition, putting performance was significantly worse in the hard relative to the easy condition in children with probable DCD, $t(1, 23) = –19.59, p < .05$, and in the TDC group, $t(1, 23) = –8.41, p < .05$. Taken together, this interaction effect shows that the putting performance of the probable DCD group deteriorated between the easy and the hard condition by a greater magnitude than that of the TDC group. This effect is illustrated in Figure 2.

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**Figure 2** — Putting performance, illustrating significant Group × Task Condition interaction. The error bars are standard error. DCD = developmental coordination disorder; TDC = typically developing children.
Body Movement

Body movement was separately analyzed in the AP and ML direction. There were no significant effects found in the ML axis; however, the effect of Group was significant for body movement in the AP axis, $F(1, 46) = 6.22, p < .05$, showing that children with probable DCD had more body movement than the TDC subjects while putting. In addition, the results showed a significant interaction effect between Group and Putting Condition in the AP axis, $F(1, 46) = 22.80, p < .05$. The $t$ tests further revealed that children with probable DCD had significantly greater AP movement compared with the TDC group in the easy condition, $t(1, 46) = –2.04, p < .05$, and in the hard condition, $t(1, 46) = –4.15, p < .05$. For the probable DCD group, body movement significantly increased from the easy to the hard condition, $t(1, 23) = 2.30, p < .05$, while for the TDC group, it was greater in the easy condition, $t(1, 23) = 4.31, p < .05$. Taken together, this interaction effect demonstrates that while the children in the TDC group decreased their body movement with increasing distance of the ball from the hole, the children in the DCD group increased their body movement, making the group differences in AP movement significantly greater in the hard relative to easy condition. This effect is illustrated in Figure 3.

Performance–Perception, Body Movement–Performance, and Body Movement–Perception Correlations

First, summing over the easy and hard conditions, putting performance was significantly and positively correlated with perceived hole size ($r = –0.66, p < .05$). The better the participants’ putting performance (shorter distance between stopped ball and hole), the larger their estimates of hole size. This effect is illustrated in Figure 4. Second, summing over the easy and hard conditions, body movement in both axes was significantly negatively related to putting performance (for AP axis, $r =$

\[\text{Figure 3} \quad \text{— Body movement in AP axis, illustrating significant Group \times Task Condition interaction. The error bars are standard DCD = developmental coordination disorder; TDC = typically developing children.}\]
Figure 4 — Correlation between putting performance and perceived hole size.

Figure 5 — Top: Correlation between AP movement and putting performance. Bottom: Correlation between ML movement and putting performance.
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-0.59, \( p < .05 \); for ML axis, \( r = -0.50, p < .05 \). The lower the magnitude of body movement in the AP and ML axes that participants displayed, the better the putting performance they achieved. These effects are illustrated in Figure 5. Third, summing over the easy and hard conditions, body movement in both axes was significantly negatively related to perceived hole size (for AP axis, \( r = -0.68, p < .05 \); for ML axis, \( r = -0.50, p < .05 \)). Body movement and perceived hole size were correlated similarly across probable DCD and TDC since the regression line (see Figure 6) fitted for both groups. The lower the magnitude of body movement in the AP and ML axes that participants displayed, the larger their estimations of the size of the hole, and vice versa. These effects are illustrated in Figure 6.

**Discussion**

In the current study, we found that perceived hole size of children with probable DCD was smaller than that of TDC. Regarding putting performance, children with probable DCD performed worse than TDC in both conditions. Perceived hole size
was positively related to putting performance; with children with probable DCD performing worse and perceiving the hole to be smaller as compared with TDC. In addition, body movement was negatively related to putting performance; probable DCD children showed more body movement and performed worse, whereas TDC showed less body movement and performed better. Last, we found a negative perception-action link: While children with probable DCD showed more body movement and perceived the hole to be smaller, TDC showed less body movement and perceived the hole to be larger.

**Children With probable DCD Less Accurately Perceived Hole Size**

Our first hypothesis, that the perceived hole size would be smaller in children with probable DCD than their typically developing counterparts, was confirmed. Many factors contribute to an individual’s perception of the size of a golf hole, the most important being optical information from the environment. As the optical information was constant and identical for both the probable DCD and the TDC groups, the disparity in perceived hole size between the two groups was not influenced by optical cues. It could be argued that an individual’s memory of the target rather than his or her actual perception of the target (Witt & Dorsch, 2009) may account for the effect of group on perceived hole size, and a growing body of research suggests that children with DCD have deficits in verbal, visuospatial short-term, and working memory (Alloway, 2007; Alloway & Archibald, 2008). However, this argument is not valid in this case because all participants had the hole within view while estimating its size. Neither optical information nor an individual’s memory can explain the group difference in perceived hole size.

**A Positive Body Movement–Perception Relationship in Children With Probable DCD and TDC**

Our second hypothesis, that children with probable DCD would have worse putting performance than TDC, was supported. In addition, our third hypothesis, that summing over groups, perceived hole size would be positively related to putting performance, was confirmed. According to the action-modulated perception account (Witt & Dorsch, 2009), an individual’s own immediate performance in a given task affects their perceptual sensitivity to task-related objects. Previous studies have demonstrated the effect of performance on perception in softball players (Witt & Proffitt, 2005), golfers (Witt, Linkenauger, Bakdash, & Proffitt, 2008), and football players (Witt & Dorsch, 2009), showing that successful performance relates positively to the perceived size of an action-related target, such as a softball, golf hole, or football goal. Our findings are in accordance with the action-modulated perception account. While children with probable DCD tended to perform worse at putting and perceived the hole to be smaller, the TDC group showed the opposite trends. The present study extends upon previous research by recruiting school-age inexperienced children and comparing the difference in the perceived size of a golf hole between children with DCD and typically developing controls.

Although the performance–perception relationship seems to be a rational explanation for differences in perceived hole size between the groups, we cannot
eliminate the argument that perception may be influenced by the participants’ preexisting differences. Johnson and Wade (2007, 2009), asked children with DCD to perceptually judge their action possibilities, such as maximum horizontal reach, vertical reach, and sitting height. Children were only required to make pure perceptual judgments without any obvious action goal. The perceptions of maximum action differed between groups. Other studies show that children with DCD have demonstrated perceptual deficits in kinesthesia (Piek & Coleman-Carman, 1995), tactility, and vision (Schoemaker et al., 2001). These studies provided empirical evidence indicating a less sensitive or accurate perception in children with DCD compared with TDC. Some previous studies have examined perceptual judgments in children with mental retardation (Block, 1993) and with learning disabilities (Whitall, Sanghvi, & Getchell, 2007) by means of requesting participants to judge their action possibility—such as maximum jumping distance and maximum clearance height—before measuring their actual maximal action performance. Nevertheless, in the current study, participants did not estimate the size of the golf hole before each putting trial. Further scrutiny is needed to determine whether the effect of group on perceived hole size is due to the difference in performance or to a preexisting difference in perception before performance. This issue could be resolved through future research comparing perceptual judgments between groups before actual action execution.

A Negative Body Movement–Task Performance Relationship for Both Groups

Our fourth hypothesis, that body movement would be negatively associated with putting performance, was also supported. Summing over both groups, higher levels of body movement during putting were related to lower putting performance, and vice versa. Overall, children with probable DCD showed more body movement and exhibited poorer putting performance, while the TDC showed less body movement and exhibited better putting performance. Riccio and Stoffregen (1988) proposed a hypothesis of function integration between postural control and behavioral goals. They contended that postural control is not an aim in itself, but only has merit to the extent that it promotes the achievements of other behavioral goals. Stemm, Jacobson, and Royer (2006) have contended that appropriately timed and sequenced weight shift, as well as appropriate postural control and balance, contribute in part to proficiency in golf. Hurrion’s (2009) study showed that professional golfers showed a significant decrease in the total amount of COP movement during putting compared with amateur golfers. The reduced COP movement displayed by the professional golfers results in greater stability and balance, which may further facilitate better putting performance. However, the relationship between COP movement and performance was unclear, as there were no measures of putting performance. In the current study, the probable DCD group had greater body movement as well as worse putting performance than the TDC group while putting in the easy condition. In addition, children with probable DCD showed more body movement while putting in the hard condition than they did in the easy condition, whereas the TDC group exhibited reduced body movement when putting in the hard condition, yielding a greater difference between the groups for body movement in the hard relative to the easy condition. Putting performance was worse in the DCD group in the hard
condition compared with the easy condition to a greater extent than in the TDC group. These findings are consistent with previous research, and demonstrate the possible role of body movement in facilitating the performance of other perceptual motor tasks (Riley, Baker, Schmit, & Weaver, 2005; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006; Stoffregen, Hove, Bardy, Riley, & Bonnet, 2007; Stoffregen, Pagulayan, Bardy, & Hettinger, 2000). Furthermore, based on the finding that during putting the amount of movement is greater for amateur golfers than for professional golfers (Hurrion, 2009), it seems that a surplus of body movement may have damaging effects on putting performance in golfers. This argument leads to another possible explanation for the interaction: that imposing high precision demands for golf putting, such as smaller hole size or longer putting distance, may result in TDC adopting a freezing degrees of freedom strategy where motor degrees of freedom (DF) are frozen or reduced for precision control of the putting movement. This strategy could give rise to an overall reduction in the magnitude of body movement, in agreement with the present results for the TDC group. Children with probable DCD may not have such a strategy, and so they amplify body movement as the distance between the golf ball and hole increases. More research is needed on comparing kinematic data between groups across various precision demands for golf putting to investigate whether children with probable DCD and TDC would employ the freezing DF strategy. In short, the present findings demonstrate a negative relationship between body movement and putting performance among children with and without probable DCD.

A Negative Perception–Action Link in Children With Probable DCD and TDC

Our prediction, that there would be negative correlations between body movement and perceived hole size for children with probable DCD and TDC, was substantiated. In the current study, we found that inexperienced young golfers’ body movement was related to their perception of hole size. Summing over the easy and the hard conditions, a greater body movement was correlated with smaller perceived size of golf hole, and vice versa. The characteristics of the perception–action link were identical for both groups; children with probable DCD have a tendency to have more body movement across putting conditions and perceive the size of the hole as smaller, whereas the TDC group has a tendency to have less body movement and perceive the size of the hole as larger. These findings were novel. However, it is a challenge for theoretical and clinical interpretations of the relationship between body movement and perceived hole size in children with probable DCD and TDC. Hurrion (2009) proposed that it is essential for a golfer to create a stable and solid base of support with a fixed pivot point to execute a putting stroke, highlighting the importance of balance and postural control. In addition, successful putting requires a golfer to visually attend to elements from the environment (i.e., distance, direction, and slope), which has major influences on their performance (Mann, Coombes, Mousseau, & Janelle, 2011). An extensive body of research demonstrates that both postural control system and visual system play roles in the performance of golf putting. It has been reported that the period of quiet eye (visual fixation on a target) is longer and the control of postural stability greater in elite compared with subelite athletes in target sports, such as golf (Hurrion, 2009; Vickers, 1992; Vine, Moore,&
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Wilson, 2011), and rifle shooting (Janelle et al., 2000; Konttinen, Lyytinen, & Era, 1999). It seems that experienced or elite athletes are able to stabilize and control their body movement and fix their vision on a target for a prolonged time during the execution of an aiming-related activity, but inexperienced or subelite athletes are not. Golfers can ensure more consistent and accurate ball strikes by holding a steadier visual focus and more stabilized body movement (Vine, Moore, & Wilson, 2011). The control of body movement and visual system are not necessarily completely independent of each other. For example, the duration of quiet eye may be influenced by poor control of body movement such as postural fatigue (Behan & Wilson, 2008). Furthermore, a study completed by Stoffregen et al. (2007) found that participants dampened their body movement during visual fixation tasks. Body movement displaces the position of the head in space, changing the position of the eyes and, hence, the direction of visual fixation (e.g., Stoffregen et al., 2006). Excessive body movement can perturb the stabilization of gaze (Lee & Lishman, 1975; Paulus, Straube, Krafszyk, & Brandt, 1989; Prado, Duarte, & Stoffregen, 2007; Stoffregen, et al., 2006; Stoffregen et al., 2007), while reduced body movement can minimize this perturbation, making it easier to maintain stable visual fixation at a target while putting, which benefits performance. This provides a possible explanation of how body movement influences perception and performance of perceptual motor tasks. The results of the current study suggest that body movement is more finely controlled by the TDC group, which may further reduce the perturbation in their visual perception of information from the environment during putting so that they can perceive hole size more accurately, whereas children with probable DCD are less able to modulate body movement to improve their visual perception of the required information. In conclusion, the findings confirm the characteristics of the perception-action link for children with probable DCD and TDC, suggesting a possible influence of body movement on perceived hole size.

Summary

To the best of our knowledge, the current study is the first to examine the relationship between perceived hole size, putting performance, and body movement in children with DCD and TDC. First of all, the results demonstrate that perceived hole size was greater and more accurate in the TDC group than in the DCD group. Second, children with probable DCD had worse putting performance than their TCD counterparts did. Third, perceived hole size was positively related to putting performance in both groups, consistent with the action-modulated account. Fourth, body movement was negatively associated with putting performance; children with probable DCD had more body movement and worse putting performance, whereas the TDC group showed the reverse. Last, greater body movement was related to smaller perceived hole size, demonstrating the characteristics of the perception-action link for both groups. Specifically, the TDC group had greater body movement and perceived the hole as larger and more accurately, while children with DCD had less body movement and perceived the hole as smaller and less accurately. It appears that children with probable DCD may be delayed in developing an effective perception-action link for golf putting. The present study has examined perception-action characteristics of golf putting in children with probable DCD and TDC.
We believe that the current study has important implications for clinical-based or educational-based interventions. Introducing a freezing DF strategy or an intervention that is principally designed to develop a more effective perception-action link while improving the performance of perceptual motor tasks in children with DCD would be a new challenge for future researchers.

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References


