Published paper
Pettit, L., Charles, J., Wilson, A.D., Plumb, M.S., Brockman, A., Williams, J.H.G. and Mon-Williams, M. (2008) *Constrained action selection in children with developmental coordination disorder.* Human Movement Science, 27 (2). pp. 286-295.
http://dx.doi.org/10.1016/j.humov.2008.02.014

Constrained action selection in children with developmental coordination disorder

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Acknowledgements: This research was partially supported by grants from Action Medical Research and Scottish Enterprise.

Abstract

The effect of advance ('precue') information on short aiming movements was explored in adults, high school children and primary school children with and without developmental coordination disorder (n = 10, 14, 16, 10, respectively). Reaction times in the DCD group were longer than in the other groups and were more influenced by the extent to which the precue constrained the possible action space. In contrast, reaction time did not alter as a function of precue condition in adults. Children with DCD showed greater inaccuracy of response (despite the increased RT). We suggest that the different precue effects reflect differences in the relative benefits of priming an action prior to definitive information about the movement goal. The benefits are an interacting function of the task and the skill level of the individual. Our experiment shows that children with DCD gain a benefit from advance preparation in simple aiming movements, highlighting their low skill levels. This result suggests that goal directed RTs may have diagnostic potential within the clinic.

Keywords: Movement, DCD, duration, reaction time, action.
PsycINFO classification: 2330 (Motor Processes).

1. Introduction

Goal-directed actions are a fundamental aspect of human movement. They can range from flicking on a light switch to hitting the correct sequence of keys whilst playing the piano – in other words they can require varying levels of skill. This paper focuses on the process of action-preparation in a simple aiming movement: selecting the appropriate effectors (limbs, joints and muscles) and determining how working point(s) need to move over time to achieve a goal under the prevailing conditions. Reaction times (RT) can provide insights into some of the fundamental processes associated with action preparation. Hick (1952) discovered that RT increases as a function of the number of possible responses (this is known as the stimulus-response uncertainty effect). More recently, however, doubts have been raised as to the generality of Hick's law. Kveraga, Boucher and Hughes (2002) found that human saccades were unaffected by stimulus response uncertainty. Wright, Marino, Belovsky and Chubb (2007) have reported that *short* aiming hand movements can be unaffected by stimulus-response uncertainty. Wright and colleagues asked participants to make short (12.7 to 17cm) movements to eight locations distributed in a semicircle on a computer screen. Although participants were presented with displays of either two or six potential targets, the authors found that the latency of the aimed hand movements was independent of uncertainty. Taken together, these studies suggest that constraining the possible action space speeds up action selection but the effect is not present with well learned movements (e.g. saccades and short aiming movements).

Constraining action selection

One tool to investigate the role of action selection in a task is through the provision of advance information (a ‘precue’) which has the potential to produce faster RTs when object location is cued in advance of the imperative stimulus to move (Rosenbaum, 1980; Goodman & Kelso, 1980; Mon-Williams, Tresilian, Bell, Coppard, Jobling, & Carson, 2001; Mon-Williams, Tresilian, Bell, Coppard, Nixdorf, & Carson, 2005; Olivier, Audiffren, & Ripoll, 1998). The precue effect has been used to study motor preparation in developmental disorders. LeClair, Pollack, and Elliot (1993) asked participants with Down Syndrome (DS) to make simple aiming movements to near or far targets. The results showed that although participants with DS had longer RTs than controls, both groups decreased RT when they were provided with partial advance information. In contrast, Mon-Williams et al. (2001) reported that participants with DS did not show a partial precue advantage in a prehension task. Mon-Williams et al. (2005) employed the same paradigm to investigate precue use in children with developmental coordination disorder (DCD). Again, children with DCD utilised complete precue information but did not benefit from partial precue information (in contrast to controls).

The findings reviewed in the preceding two paragraphs paint a somewhat complex picture. Adolescents with DS show a partial precue advantage when carrying out a simple aiming task but not a more complex prehension task. Normal adults show a partial precue advantage when carrying out a complex Hick’s type task and prehension but not a simple aiming task. These results suggest that the benefits of precue information are a function of an individual’s skill level and the task, with these two factors interacting. We suggest that this pattern is best understood by considering the benefits conferred when constraining an action space. Reducing (constraining) the number of possible complex actions may not be beneficial to an individual with low levels of skill because the remaining action space is still too large. Conversely, a reduction in the number of possibilities in a simple action may not provide much benefit to a highly skilled individual - either because the space is already sufficiently constrained or because the benefits have become too small to outweigh the cost of priming an action in advance. If this interpretation is correct, it suggests that children with DCD might show a partial precue effect in a simple aiming movement despite the fact that they show no such effect in a prehension task (Mon-Williams et al 2005).

We decided to test whether children with DCD would show a precue effect in a simple aiming task. Participants were required to make aiming movements to one of eight possible targets under four conditions which differed in terms of the amount of advance precue information provided; *no* information, *low*, *moderate*, or *high* quality information. Targets were arranged in a semi-circle at a distance of 10 cm from the starting point. The work of Wright et al. (2007) suggests that there should be little effect of stimulus response uncertainty in adults at such short target distances (<12 cm). It was anticipated, however, that the provision of advance information would be advantageous (and decrease RT) in young children. Moreover, this effect should be even greater for children with known movement difficulties (DCD).

2. Method

2.1. Participants

Participants comprised four separate groups; a) neurologically intact adults, b) neurologically intact high school children, c) neurologically intact primary school children, and d) children clinically diagnosed with developmental coordination disorder (DCD). The adult group consisted of 10 undergraduates from the University of Aberdeen aged between 21 and 25 years (5 males and 5 females) who volunteered to participate in the study. The high school sample consisted of 14 children recruited via a local high school, aged between 13 and 16 years (8 males and 6 females). The primary school group comprised 10 children recruited via a local primary school, aged between 7 and 10 years (4 males and 6 females). The DCD group consisted of 16 children (13 males and 3 females), aged between 7 and 13 years (m=10). All children in this group clinically met DSM-IV criteria for DCD and scores on the Movement ABC (MABC) were below the 1st percentile. These children were recruited via the Occupational Therapy department at the Royal Aberdeen Children's Hospital. The other experimental groups were not formally tested for IQ or motor performance, but none had a history of any sensory, motor or neurological problems. The teachers and parents reported that the control children were performing at an age appropriate level in physical, educational and social settings. In addition, all participants were reported to have normal or corrected to normal vision. Participants (and parents where appropriate) provided their informed consent prior to their inclusion in the study. The study was approved by a University ethics committee and was performed in accordance with the ethical standards laid down in the Declaration of Helsinki.

2.2. Apparatus

Movements were tracked using an Ascension mini-bird magnetic measurement system. A marker was placed on the tip of the participant's index finger using micropore tape and participants were seated at a wooden table positioned at a minimum distance of 4 feet from metal objects so as to avoid interference with the electromagnetic field. Movements were sampled at 100 Hz and were recorded for 10 seconds. The data were first filtered using a dual-pass Butterworth second order filter with a cut-off frequency of 16 Hz (equivalent to a fourth order zero phase lag filter of 10 Hz), and, the tangential speed of the marker was computed. These data were used to determine the onset and offset of the movement using a standard algorithm (threshold for movement onset and offset was 5 cm/sec). These signals were also used to determine the final spatial location of the index finger. Custom analysis routines were used to compute the dependent variables of interest in this study. RT was calculated as the delay between imperative stimulus onset and movement onset and movement time was taken as the time from the onset of movement until the offset of the movement. The final finger position was recorded in Cartesian (x,y) coordinates and used to determine a root mean square error from the target location.

The experimental stimuli were presented on a laptop with the screen positioned along the horizontal plane. The laptop sat on a table at a distance of approximately 20 cm from the seated participant so that participants could perform aiming movements comfortably on a horizontal surface. Stimulus presentation consisted of a central cross that was surrounded by 19 green precue circles arranged in a semi-circle (see Fig. 1). The precue circles were equidistant from the central cross (distance from centre = 105 mm, diameter of circles = 7.5 mm). Eight of the circles were possible target locations (every second circle with the exception of the middle one). The imperative stimulus was the disappearance of all green precue circles and the appearance of a red target circle. The electromagnetic recording equipment and the stimuli presentation were electronically time-locked.

[Insert Fig. 1 about here]

2.3. Procedure

The experimental task required participants to make simple aiming movements to one of the eight target locations presented in four different precue conditions: no-, low-, moderate-, and high-quality advance information: see Fig. 1. Two aiming movements were made to each target in each precue condition, resulting in each participant completing 64 trials in total. The order of trials (target location and precue condition) was fully randomised for each participant.

Participants were seated in front of the laptop display, with their midline in line with the central cross. First of all, participants viewed a preliminary “ready” screen that displayed the central cross where they placed the index finger of their preferred hand (as determined by the hand used for writing). The experimenter then electronically triggered stimulus presentation and the kinematic recording. The next screen then displayed a semi-circular array of green circles. Participants were instructed to observe the display (and possible subsequent displays) until they saw a single red circle, which was their target. On presentation of the imperative stimulus, participants were instructed to move their index finger to it as quickly and as accurately as possible. The red target circle remained on the screen until the next trial was initiated. Once the movement recording was completed, participants returned their index finger to the central cross and the experimenter started the next trial. All participants were given several practice trials before test trials commenced.

[Insert Fig. 2 about here]

All precue displays were presented for 1500 ms, however the number of precue displays varied across advance information conditions (see Fig 2): In the *no* advance information condition, only one precue screen was presented and this consisted of the full 19 green circles (100%). This display was immediately followed by presentation of one of eight possible imperative target circles. In the *low* quality advance information condition, the 100% precue screen was presented, followed by a display in which the number of green circles was reduced to 50% (thus indicating in which half of the screen the target would be presented). This display was immediately followed by the presentation of one of 4 possible targets. In the *moderate* quality advance information condition, the 100% and 50% screens were presented, followed by a display in which the number of green circles was reduced to 25% (indicating in which quarter of the semi-circle the target would appear). This display was immediately followed by the presentation of one of two possible targets. In the *high* quality advance information condition, the 100%, 50%, and 25% precue screens were presented, followed by a display in which the number of green circles was reduced to three (providing full precue information about the target location, as the target was always the centre dot). This display was followed by the presentation of the single red imperative target.

3. Results

3.1. Data reduction and inferential analyses

For each experimental group, mean reaction time, movement time, and final spatial location (for the adult group only) was calculated from trials at each target position in each precue condition. Trials in which participants had made an obvious error or had moved before presentation of the target were eliminated from the data set. One participant in the DCD experimental group made too many erroneous movements to produce reliable data, and so had to be removed from the analyses. The adult data were first entered into repeated measures ANOVA with target position and precue condition as within-subjects factors. Separate ANOVAs were conducted for each dependent variable. Subsequently, all data were entered into a mixed factor ANOVA using target position and precue condition as within-subject factors and experimental group as a between-subjects factor. Separate ANOVAs were conducted for each dependent variable.

3.2. Adults

Reaction time was unaffected by precue condition [F (3,27) = 0.20, p = 0.90, eta squared = 0.02], revealing that there was no advantage of advance information. There was no effect of precue condition on movement time [F(3,27) = 1.38, p=0.27, eta squared = 0.13] demonstrating that both the preparation and execution of the movements were unaffected by the provision of advance information. The data from the 50% precue condition were analysed separately to explore whether there was an effect of target position in this condition. There was no effect of target position on reaction time [(F(7,63) = 0.91, p = 0.50), eta squared = 0.09]. Likewise, target position had no significant effect on movement time [(F(7,63) = 0.78, p=0.61), eta squared = 0.08].

Comment [ADW1]: What?

3.3. All experimental groups

The RT data showed a significant interaction between group and condition [(F(9,135) = 2.84, p<0.05), eta squared = 0.16], revealing that experimental groups were affected differently by precue condition. The effect of precue on reaction time was explored by conducting ANOVAs on the individual groups. Further analyses revealed that the high school children's RTs were unaffected by condition [(F(3,39) = 0.30, p=0.83), eta squared = 0.02] in the same way as reported earlier for adults. In contrast, primary school children exhibited a significant effect of precue condition [(F(3,27) = 5.79, p<0.01), eta squared = 0.39], and this effect was also found in children with DCD [(F(3,42) = 5.55, p< 0.01), eta squared = 0.28]. Fig. 3 shows that children with DCD are affected most by the provision of precue information; as precue quality increases, their reaction times decrease in a linear fashion. In order to formally test this effect, we used linear regression to determine the reduction in RT as a function of information for each individual child. We then used one-way ANOVA to test the RT reduction between the primary school children and the DCD population. This analysis showed a reliable group difference between these populations (F(1,24) = 5.35, p<0.05).

[Insert Fig. 3 about here]

The movement time data did not reveal a significant interaction between group and condition. Movement time was unaffected by precue condition [(F(3,135) = .02, p = 0.99), eta squared = 0.00] and thus independent of the quality of advance information.

However, movement time was significantly affected by group, [(F(3,45) = 7.35, p<0.01), eta squared = 0.33] (see Fig. 4). Overall, primary school children took significantly longer to complete movements than adults [(F(1,18) = 8.35, p=0.01), eta squared = 0.32] and high school children [(F(1,22) = 14.9, p<0.01), eta squared = 0.40]. Children with DCD took significantly longer than high school children [(F(1,27) = 8.34, p< 0.01), eta squared = 0.24] but actually exhibit significantly faster movement completion times than control primary school children [(F(1,23) = 4.47, p<0.05), eta squared = 0.16].

[Insert Fig. 4 about here]

The reason that the children with DCD showed shorter movement times became apparent in the spatial error data where there was no interaction but a significant effect of group was found [(F (3,42) = 13.82, p<0.01), eta squared = 0.50] (see Fig. 5). Children with DCD produced significantly more spatial error than adults [(F(1,23) = 7.79, p=0.01), eta squared = 0.25], high school children [(F (1,26) = 35.1, p<0.01), eta squared = .57] and control primary school children [(F(1,21) = 15.26, p<0.01, eta squared = 0.42]. The difference between high school children and adults was also significant [(F(1,21) = 6.4, p<0.05), eta squared = 0.23]. No significant effect of precue condition was observed for spatial error [(F (3,126) = 1.60), p=0.19, eta squared = 0.04].

[Insert Fig. 5 about here]

4. Discussion

The current study investigated the effect of advance information on simple aiming movements in an attempt to investigate action selection in adults, typically developing children and children with DCD. The results showed no effect of precue condition on the adults' reaction times. It is not possible to determine whether the lack of an effect represents a ceiling effect (i.e. whether the no information reactions were at some upper limit so it simply wasn't possible to respond faster) or a floor effect (i.e. where faster reactions were possible with advance preparation but the costs of such a strategy outweighed the benefits). In either case, the interpretation is the same – the advance information did not provide a large enough benefit to reduce RT. These results constitute a violation of Hick's law (i.e. RT was not a function of response uncertainty). This result is consistent with the work of Kverga et al. (2002) and Wright et al. (2007) who showed, respectively, that eye saccades and short aiming movements violate Hick's law. In other words, RTs for well learned and highly practiced movements are unaffected by the number of possible target locations. It follows that Hick's law is restricted to movements (responses) where constraining action selection is useful to the achievement of the goal. In these terms, Hick's law relates to stimulus-response-selection benefits.

In the introduction, we suggested that response-selection benefits are a function of the task and the skill level of the individual. It is known that adults show a partial precue effect in a prehension task whilst adolescents with DS and children with DCD do not (Mon-Williams et al 2001; Mon-Williams et al 2005). LeClair, Pollack, and Elliot (1993) showed that a DS population do show a partial precue effect in a simple aiming task. Thus, we predicted that individuals with lower skill levels would show a partial precue effect in a simple aiming task. In line with this prediction, a significant RT advantage was found in control primary school children when the precue information reduced the number of potential targets from eight to four (i.e., in the 50% condition). Thereafter, the control primary school children displayed no further RT advantage despite the provision of increasingly specific information. In contrast, children with a known movement deficit (DCD) displayed a linear decrease in RT as the quality of the advance information increased. In other words, increasing the precue information allowed the necessary action to be selected more quickly. Notably, this effect even occurred between the moderate and high quality information condition where the number of possible target locations was reduced from two close targets to only one. The current experiment therefore helps clarify the complex picture drawn by previous results, by demonstrating that children with DCD can benefit from partial pre-cue information (contra Mon-Williams et al, 2005) if the benefits outweigh the costs. This trade off is relative to skill level, and aiming is clearly easier than prehension.

Children with DCD were overall less skilled in producing these simple aiming movements, as indexed by by the low spatial accuracy at the end of their movements. Inspection of the signed spatial errors revealed that the children tended to land short of the actual target location. The same instruction was provided to all of the groups (move as quickly but as accurately as you can) but it is possible that the kinematic differences are a function of how the children with DCD interpreted the task. Likewise, differences associated with the significance of the task are likely to explain why the high school children showed higher performance levels (shorter duration with higher spatial accuracy) than a group of undergraduate students. It is always difficult to disambiguate differences in performance mechanisms from disparities in interpreting the instructions and the significance associated with a task (Tresilian et al., 2005). Nevertheless, it is notable that only the DCD population consistently failed to achieve the core goal of ending the movement with their finger in contact with the imperative target.

We would suggest the paradigm reported in this manuscript provides a very efficient manner of identifying children with DCD. The children with DCD showed RTs that differentiated them from all of the (randomly selected) control children. This observation opens up the exciting prospect that simple clinical kinematic assessment techniques could be used to identify children at risk of motor problems within educational or clinical settings.

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Figure Captions

Figure 1. Stimuli presentation and precue conditions

100% Condition – Target Probability = 1:18 (no advance information);
50% Condition – Target Probability = 1:9 (low quality advance information);
25% Condition – Target Probability = 1:5 (moderate quality advance information;
12.5% Condition – Target Probability = 1:3 (high quality advance information).

Figure 2. Sequence presentation in the four precue conditions

Figure 3. Effect of precue condition on reaction time across experimental group

Figure 4. Movement time across experimental group

Figure 5. Spatial error across experimental group

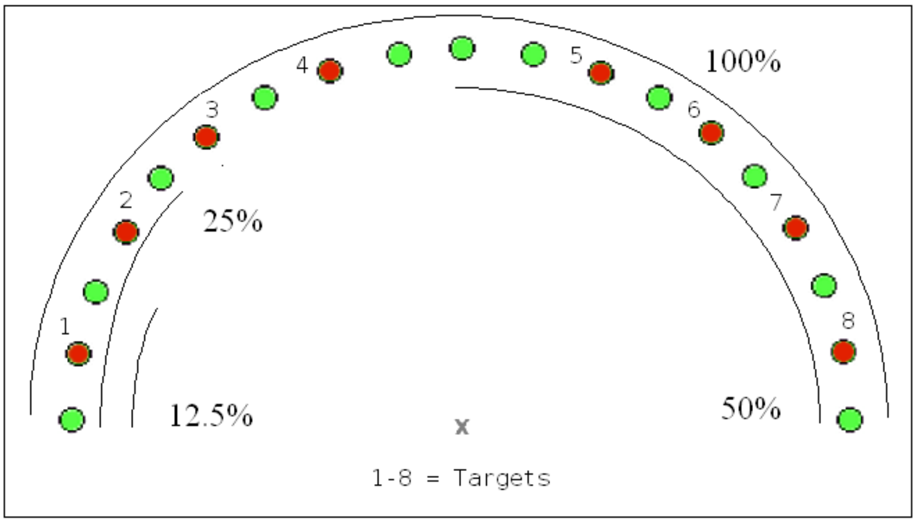

Figure 1

Constraining action selection

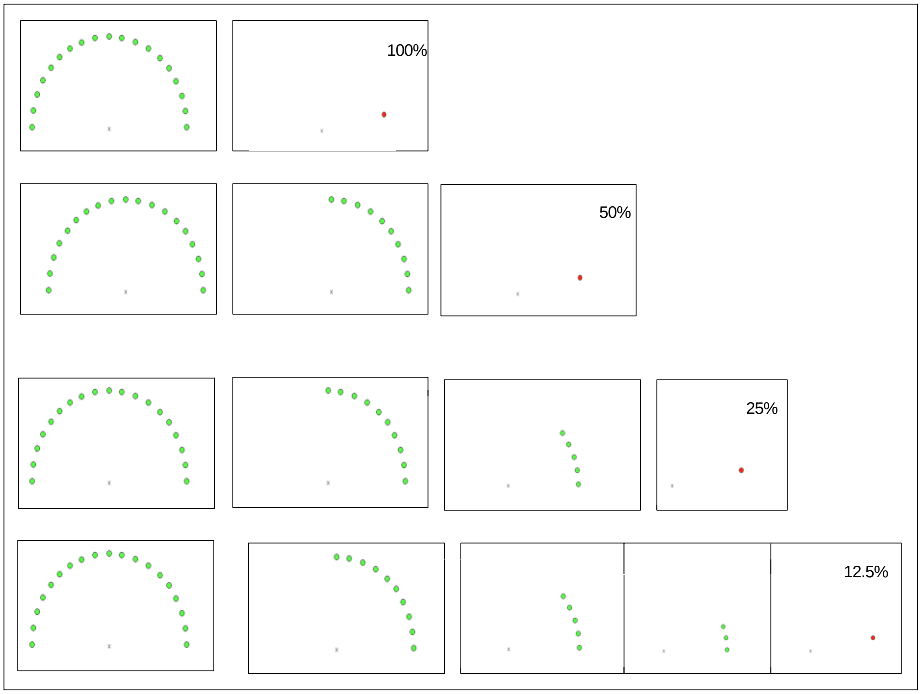

Figure 2

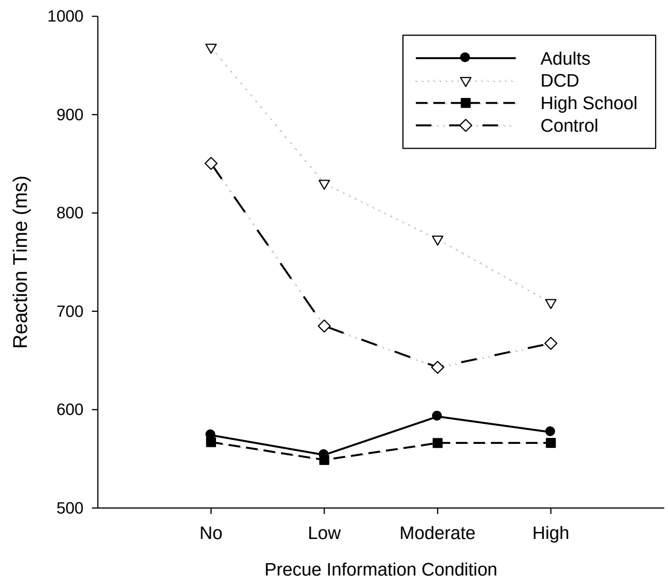
1000
900
800
700
600
500
Reaction Time (ms)
No
Low
Moderate
High
Precue Information Condition
Adults
DCD
High School
Control

Figure 3

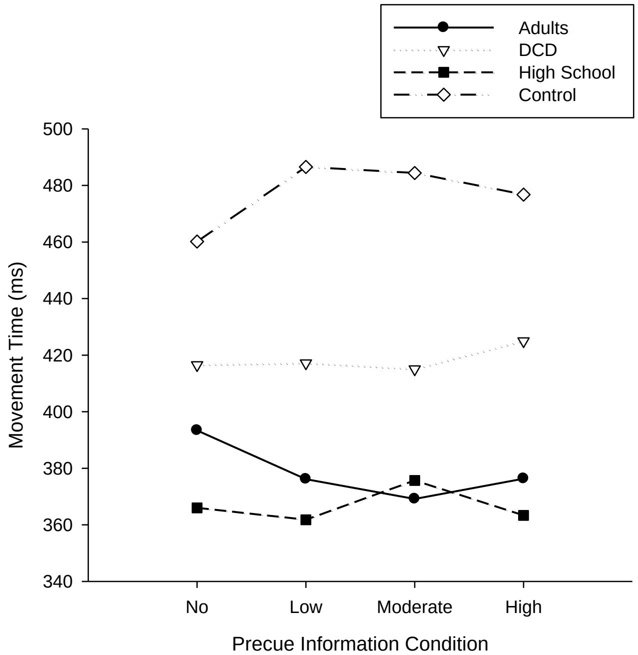
Adults
DCD
High School
Control
500
480
460
440
420
400
380
360
340
Movement Time (ms)
No
Low
Moderate
High
Precue Information Condition

Figure 4

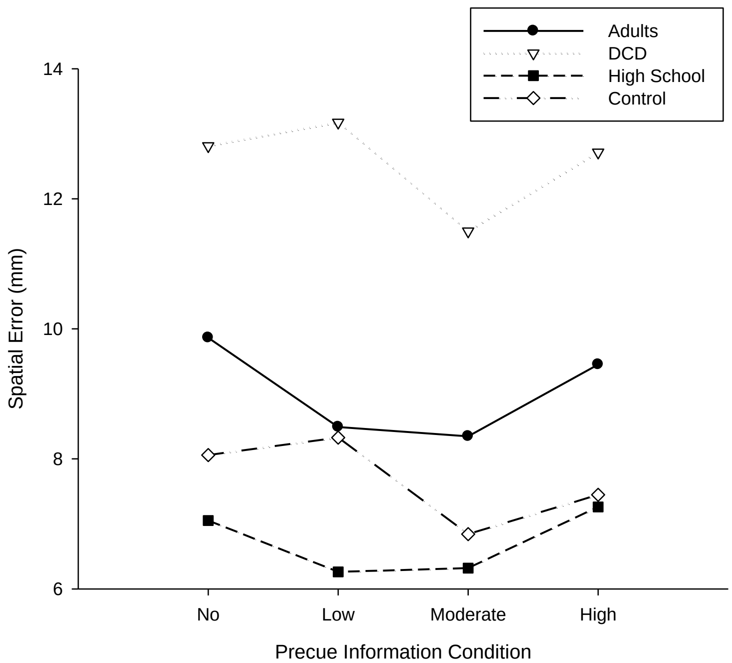
Adults
DCD
High School
Control
14
12
10
8
6
Spatial Error (mm)
No
Low
Moderate
High
Precue Information Condition

Figure 5