Multi-limb coordination and rhythmic variability under varying sensory availability conditions in children with DCD

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Abstract

Children with Developmental Coordination Disorder (DCD) have sensory processing deficits; how do these influence the interface between sensory input and motor performance? Previously, we found that children with DCD were less able to organize and maintain a gross motor coordination task in time to an auditory cue, particularly at higher frequencies [Whitall, J., Getchell, N., McMenamin, S., Horn, C., Wilms-Floet, A., & Clark, J. (2006). Perception–action coupling in children with and without DCD: Frequency locking between task relevant auditory signals and motor responses in a dual motor task. *Child: Care, Health, and Development*, *32*, 679–692]. In the present study, we examine the same task (clapping in-phase to marching on a platform) under conditions involving the removal of vision and hearing. Eleven children with DCD (mean = 7.21, SD = 0.52 years), 7 typically developing (TD) children (mean = 6.95 ± 0.72 years), and 10 adults performed continuous clapping while marching under four conditions: with vision and hearing, without vision, without hearing, and without both. Results showed no significant condition effects for any measure taken. The DCD group was more variable in phasing their claps and footfalls than both the adult group and the TD group. There were also significant group effects for inter-clap interval coefficient

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of variation and inter-footfall interval coefficient of variation, with the DCD group being the most variable for both measures. Coherence analysis between limb combinations (e.g., left arm–right arm, right arm–left leg) revealed that the adults exhibited significantly greater coherence for each combination than both of the children's groups. The TD group showed significantly greater coherence than the DCD group for every limb combination except foot–foot and left hand–right foot. Measures of approximate entropy indicated that adults differed from children both with and without DCD in the structure of the variability across a trial with adults showing more complexity. Children with DCD are able to accomplish a self-initiated gross-motor coordination task but with increased variability for most but not all measures compared to typically developing children. The availability of visual and/or auditory information does not play a significant role in stabilizing temporal coordination of this task, suggesting that these are not salient sources of information for this particular task.

1. Introduction

The ability to move adaptively within one's environment is a fundamental part of daily life that many of us take for granted. Nevertheless, many ostensibly simple activities can prove hopelessly frustrating for a child who lacks the movement competence to function effectively within his or her environment. While such children have previously been described as "clumsy" or "uncoordinated", the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders IV* now recognizes Developmental Coordination Disorder (DCD) as a common label for such impairments (APA, 1994). The prevalence of DCD has been estimated to be as high as 6% for children in the age range of 5–11 years (APA, 1994) yet the underlying structure of these impairments is less clear. One suggested influence on motor coordination in children with DCD is their ability to couple sensory information to appropriate motor action.

The exploration of sensorimotor interaction has a long history in the extant literature of children with DCD, as there is evidence of deficits in visual-motor (e.g., Brenner, Gillman, Zangwill, & Farrell, 1967; de Castelnau, Albaret, Chaix, & Zanone, 2007; Zoia, Castiello, Blason, & Scabar, 2005), kinaesthetic-motor (e.g., Bairstow & Laszlo, 1981; Laszlo & Bairstow, 1988) and auditory-motor (e.g., Volman & Geuze, 1998) coupling. In a previous study, we demonstrated that, while performing the task of simultaneously clapping and marching, children with DCD had more difficulty coupling all four limbs to an external auditory signal than age matched typically developing (TD) children (Whitall et al., 2006). Significant deficits were seen in both limb coordination and synchronizing with the beat. However, it was not clear whether the performance deficits were due to a fundamental inability to intrinsically coordinate the limbs together (without external cues) or to the inability to couple the external cues to motor responses with a consequent effect on limb coordination. In addition, the influence of *withdrawing* one sensory input on a given motor response remains understudied. In the present parallel study, we investigated the so-called intrinsic coordination of this gross-motor task by asking that it be accomplished without external cues and by systematically withdrawing available sources of information.

In earlier studies with TD children, we found a developmental trend towards more stable coordination patterns over the age range of 4–10 years in self-selected clapping and walking (Getchell, 2006; Getchell & Whitall, 2003). Further, children with learning disabilities and motor problems – but not specifically diagnosed with DCD – performed this dual-motor task less stably and, unlike typically developing children, did not entrain their limbs to exhibit absolute (i.e., high coupling between hands and feet) coordination patterns even after short-term practice of this dual-motor task (Getchell, McMenamin, & Whitall, 2005). However, while these previous results do guide predictions in the present study, there is a subtle difference between the two sets of studies aside from the change from walking to marching. In the previous studies, adults and children were not given a specific instruction about what type of coordination to adopt (e.g., to "time" their hands and feet together) since we were interested in whether or how the limbs would "self-organize" into a particular absolute or relatively coupled four oscillator system. It is plausible that we would find different results when the type of coupling (absolute) is specified at the beginning.

In order to accomplish the specific instruction to march and clap at the same time in an even rhythm a child must first understand the instruction in addition to being able to do both marching and clapping independently. Subsequently, to produce an accurately coordinated action, he or she would need some kind of internal template or reference model of what it feels like to time the hands and feet actions together in an even rhythm. Tuning of this template would require sensory information which, in a self-selected speed task, could come from four possible sensory sources: proprioceptive information of muscle and joint actions; somatosensory information from touching the ground (step) or the other hand (clap); auditory information from hearing the steps and/or claps; and visual information – probably from observing the hands since the feet are more difficult to see. In the present study we systematically removed the available auditory and visual feedback to determine if either of these sources of information contributed to the overall motor response to instruction. We reasoned that intrinsic auditory information might be important because, as an external source of information, it has a greater effect on increasing the consistency of tapping than either a visual display or tactile information in adults (Kolers & Brewster, 1985). Therefore, since adults have presumably constructed a more stable internal model for producing coordinated movements, children – particularly children with DCD – might be more affected by removing this source of intrinsic feedback. Visual information gained from looking at the hands clapping was presumed to be less important for fine-tuning motor responses at all ages unless individuals have learned to rely upon it in lieu of other sources of information. This result would essentially be a re-weighting of sensory information wherein vision has become the dominant source.

Thus, the specific aims of this study are to determine if children with DCD can produce a stable performance while intrinsically coordinating self-paced clapping and marching and whether this performance is maintained when presumably task-relevant sensory information (visual and auditory) is not available to them. By comparing conditions involving the withdrawal of vision and/or hearing to a baseline with a full sensory-available condition and by comparing the DCD group to adults and age-matched peers, we aimed to determine how children with DCD respond to sensory withdrawal in terms of gross-motor coordination and if they respond differently than typically developing children and/or adults. We hypothesized that the performance of children with DCD compared to typically developing children would be less stable under normal sensory conditions indicating

a problem with intrinsic coordination and not primarily a problem with synchronization to a signal. We also predicted that children with DCD would be differentially less stable in the sensory withdrawal conditions, particularly when auditory feedback is withdrawn, indicating a higher dependence on available auditory information for the performance of this task.

2. Materials and methods

2.1. Participants

Eleven children with DCD (mean age: 7.2 ± 0.5 years; 7 boys, 4 girls), 7 typically developing (TD) control children (mean age: 7.0 ± 0.7 years; 4 boys, 3 girls), and 10 adults (age range: 18–30 years; 7 males, 3 females) participated in this study (see Table 1). All participants were informed of their rights as human subjects and all testing obtained Institutional Review Board approval. Adult participants signed an informed consent and parental consent was obtained for children.

Participants in the DCD group were recruited through physical or occupational therapists as having motor difficulties by (1) scoring on the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992) at or below the 10th percentile, and (2) showing normal cognitive ability as assessed by the Woodcock–Johnson Revised Cognitive Ability Early Development Scale (Woodcock & Johnson, 1989, 1990). Exclusion criteria included (APA, 1994) (1) the presence of coordination difficulties due to a general medical condition such as cerebral palsy, hemiplegia, or muscular dystrophy; and (2) meeting the criteria for a Pervasive Developmental Disorder. Exclusion Criteria were assessed by way of parental questionnaires in conjunction with a neuro-developmental examination given by a pediatric physician. While there is no ''gold standard'' for identifying children with DCD, the majority of recent studies on this population have used the MABC for identification (Henderson & Barnett, 1998; Wilson & McKenzie, 1998). The Woodcock–Johnson Psycho-Educational Battery – Revised (Woodcock & Johnson, 1989, 1990)

Table 1
Age, gender, and MABC percentile scores for DCD and TD participants

DCD				TD			
SS #	Age	Sex	MABC %	SS #	Age	Sex	MABC %
1	6.17	M	<1	2	6.00	M	36
2	7.83	F	22[a]	4	7.17	F	40
3	7.08	F	2	11	6.33	F	22
4	7.00	M	<1	12	6.42	F	39
5	7.58	M	<1	16	8.00	M	49
6	6.75	F	<1	18	6.83	M	96
7	7.58	M	6	23	7.58	M	65
8	7.08	M	11				
9	8	M	<1				
10	7.08	F	2				
11	7.25	M	13				

[a] Participant diagnosed with DCD by pediatrician.

assesses overall cognitive development and specific underlying intellectual processes including the presence of learning difficulties (Woodcock & Mather, 1989, 1990).

Participants in the TD control group were selected from a population of friends and schoolmates of the children with DCD. All control participants (1) scored between the 40th and 90th percentiles on the MABC and (2) were of normal intelligence as assessed for the DCD group. The presence of an identified learning disability was the only exclusion criterion for the control group and none were so excluded. Cognitive percentage scores for the Woodcock–Johnson Revised Cognitive Ability Early Developmental Scale did not differ between groups (55.1% for DCD group and 48.6% for TD group). All children had psycho-educational assessments and neuro-developmental exams given at the University of Maryland's Center for Development, Behavior and Learning by qualified personnel. Adult participants in the study were included for the sake of developmental comparison and were not subject to rigorous inclusion or exclusion criteria beyond the required ability to complete all tasks in the experiment and the exclusion of those with extensive musical background defined by at least 6 months of training.

2.2. Experimental protocol

Upon arrival, participants were given a period of time to get used to the surroundings while the parent read and signed the consent form approved by the University of Maryland – Baltimore Institutional Review Board. Participants were then asked to march on a wooden platform of dimensions 107 cm length, 107 cm width, and 15.5 cm height over a smaller towel covered surface of 41×40 cm while clapping two cymbals together under four separate conditions involving the occlusion of vision and/or hearing. Cymbals have the advantage of providing a louder sound as well as keeping the children in a more symmetrical clapping pattern (i.e., they are less likely to hold one arm fixed and clap with the other) with shoulder and elbow joints around 90°. Participants were also encouraged to lift their knees to 90° while marching.

Vision was occluded by a blindfold while large headphones that emitted white noise occluded hearing. Rest periods were provided approximately every 10 min unless the child's behavior dictated a need for extra rests. Stickers were provided to the children to motivate more attentive participation. All four conditions were randomized within a block, and blocks were repeated a total of four times with the same within-block order to gain a measure of stability across trials. Each trial lasted 25 s and only data from the last 20 s of each trial were used in the analysis. From pilot work, we established that 25 s was long enough to produce a steady state but short enough to avoid boredom and fatigue.

2.3. Apparatus

Data were collected using a Flock of Birds magnetic tracking system (Ascension Technologies, Burlington, VT, USA) and software by the MotionMonitor magnetic tracking system (Innovative Sports Training, Inc., Chicago, IL, USA). Sensors were placed on the dorsum of the hands and above the toe area on the feet, as we reasoned that the toes would touch the ground first. Data was sampled at 100 Hz and analyzed using custom software written in LabVIEW 7.1 (National Instruments) and MATLAB (The Math-Works, Inc.).

2.4. Measures

We assessed the average coordination exhibited by participants within a trial and also the stability of this performance as measured by four sources of variability/consistency which represent increasingly detailed analysis of the overall stability of the coordination.

Mean relative phasing (MRP) represents the average temporal relationship between clap and footfall calculated over a trial. It is expressed as a percentage of step cycle in which the clap occurred. For any given step cycle, the goal of the task was in-phase coordination where step and clap occurred simultaneously; in this case, relative phase would be 100%. Relative phase was calculated for each step cycle within a trial and these values were then averaged across trials within each condition to get MRP. Values were justified to 100% in order to be compared; thus, for example, a MRP value of 5% (which indicates the clap follows the heel strike) was justified to 105%, and if three phasing points of 80, 85, and 5 were given for a trial, these would be analyzed as 80, 85, and 105.

Variability of relative phasing (VRP) is the standard deviation around the mean phasing and is one indication of the stability of a system (Kelso & Schöner, 1988). VRP was calculated within each trial and then averaged across trials within each condition.

Inter-clap interval (ICI) is the period between any two claps in a given trial. Similarly, inter-footfall interval (IFI) is the period between two consecutive steps. Within-trial means and standard deviations were calculated for each of these measures. *Coefficient of variation* (CV) was calculated as the standard deviation divided by the mean.

To examine the degree of coupling or consistency between the limbs in terms of the frequency at which they were marching/clapping, we also performed maximal coherence analysis. Coherence should be italicized for parallel structure to other measures. Coherence is similar to correlation but is performed in the frequency domain. Specifically, it determines the degree to which the phase relation between two signals (for example, the right foot and right hand) is constant over a given frequency range of the power spectrum. Power spectral density analysis was calculated using Welch's averaged periodogram method (The MathWorks, Inc.; Hanning window; bin width = 0.3906 Hz). The peak coherence below 2 Hz and phase relation of the peak coherence were then determined for each hand–foot combination.

The final measure of stability was an examination of the complexity of the time-series signals using *Approximate Entropy* (ApEn – run length $m = 2$; filter width $r = 0.2$; Pincus, 1991; Pincus & Goldberger, 1994). ApEn determines the degree to which a signal contains sequential structure, i.e., repeating patterns over time. It yields a value close to 0 for highly regular, predictable signals such as a sine wave and a value close to 2 for highly irregular, unpredictable, more complex signals such as white noise. This allowed us to determine the degree of uncertainty or variability in each of the oscillating limbs over the course of a trial.

2.5. Statistical analysis

A repeated-measures MANOVA was employed to test for condition differences and group differences on the dependent variables listed above. Significant effects were investigated post hoc by way of Tukey's HSD test. Significance for all effects was set at $p \leqslant .05$. All statistical analysis was completed using SPSS 12.0 and 13.0.

3. Results

3.1. Phasing

There was no significant group or condition effect on MRP (Group: $F(2, 25) = .218$, $p = .806$; condition: $F(3, 23) = .876$, $p = .457$). Group averages for mean relative phase ranged from 81% to 84% across conditions for adults, 76% to 77% for control children, and 77% to 78% for children with DCD. A significant group effect was noted on VRP across all conditions, $F(3, 23) = 17.05$, $p < .001$ (Fig. 1). Post hoc analysis revealed that the DCD group was more variable within trials than both the adult group and the TD control group regardless of feedback condition. The DCD group was also more variable across trials (four for each condition) than the adult and TD groups, $F(2, 25) = 8.98$, $p < .001$.

3.2. Period

Inter-clap interval. No significant effects were noted on mean ICI (Group: $F(2, 25) = 0.185$, $p = .542$; condition: $F(3, 23) = 0.689$, $p = .568$). Group averages for mean ICI ranged from .69 to .70 s across conditions for adults, .73 to .76 for control children, and .79 to .83 for children with DCD. There was, however, a difference between groups on ICI CV in that the DCD group was significantly more variable within trials than both other groups, $F(2, 25) = 23.33$, $p < .001$ (Fig. 2). No sensory condition effects were noted on ICI or ICI CV.

Inter-footfall interval. Given the similarity between right to left and left to right inter-footfall interval (IFI) data, only left to right IFI data is reported here. In comparing groups for IFI, no significant effects were noted. Group averages on mean IFI ranged from .68 to .69 s across conditions for adults, .71 to .75 s for control children, and .75 to .78 s
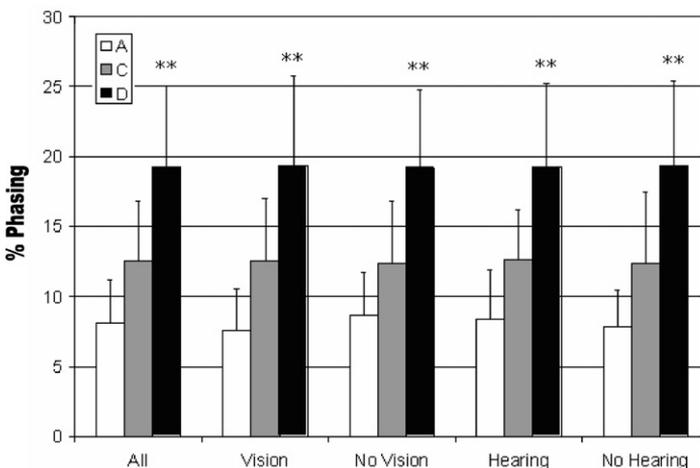

Fig. 1. Variability of relative phasing showed the DCD group to be significantly more variable than the adult and TD groups in phasing their claps with their footfalls. The removal of vision and hearing had no effect on variability within trials. A = adult participants, C = typically developing children, D = children with DCD.
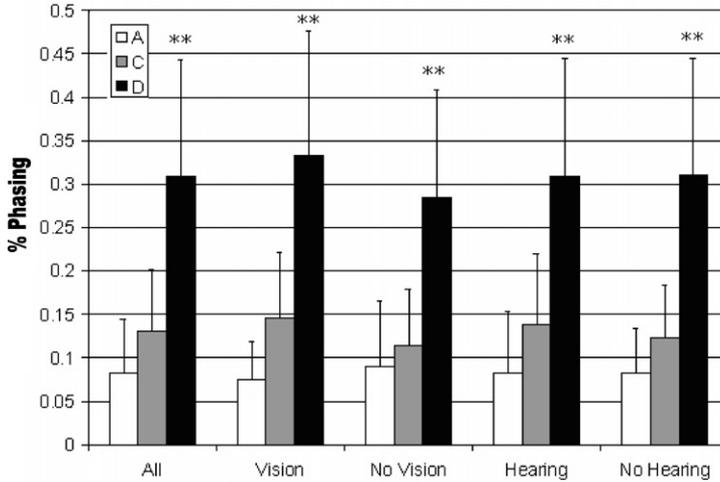
Fig. 2. Coefficient of variation for ICI. Participants with DCD showed significantly higher coefficients of variation for inter-clap interval than TD and adult participants. This measure accounts for the slightly longer average period between claps observed in the DCD group. The removal of vision and hearing had no effect on CV of ICI. A = adult participants, C = typically developing children, D = children with DCD.

for children with DCD. However, there was a group effect for IFI CV, $F(2, 25) = 12.97$, $p < .001$ (Fig. 3), with the DCD group being significantly more variable than the TD and adult groups, which were not different from each other. No sensory condition effects were observed on any IFI-related measure.
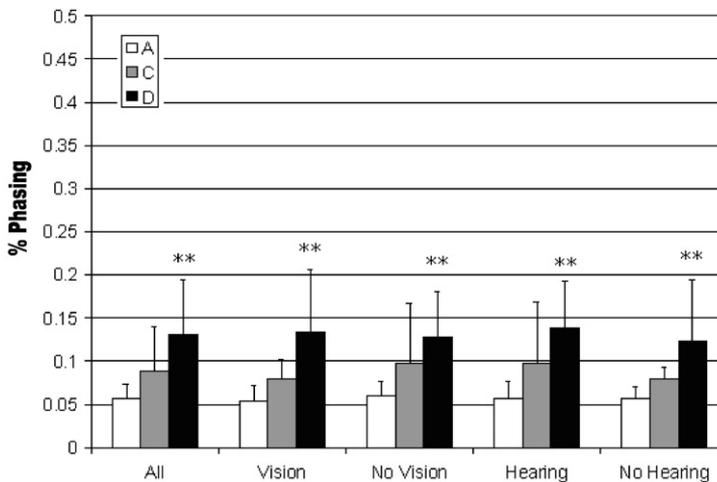

Fig. 3. Coefficient of variation of IFI. Participants with DCD showed significantly higher coefficients of variation for inter-footfall interval than TD and adult participants. This measure accounts for the slightly longer average period between steps observed in the DCD group. The removal of vision and hearing had no effect on CV of IFI. All participants were less variable in their marching than in their clapping (Fig. 2). A = adult participants, C = typically developing children, D = children with DCD.

3.3. Coherence

The maximum coherence between each of the six combinations of limbs for the three groups of participants across all conditions is shown in panels A, B, and C of Fig. 4. We merged conditions for these representations given the lack of any condition effect on coherence. Significant group effects for all couplings were as follows: right hand and left hand, $F(2, 25) = 21.69$, $p < .001$; right foot and left foot, $F(2, 25) = 16.31$, $p < .001$; right hand and right foot, $F(2, 25) = 31.26$, $p < .001$; left hand and left foot, $F(2, 25) = 46.23$, $p < .001$; right hand and left foot, $F(2, 25) = 48.51$, $p < .001$; and left hand and right foot, $F(2, 25) = 44.63$, $p < .001$. Post hoc tests revealed that the adults exhibited significantly greater coherence between all combinations of limbs than the children's groups. Further, the control children exhibited significantly greater coherence between
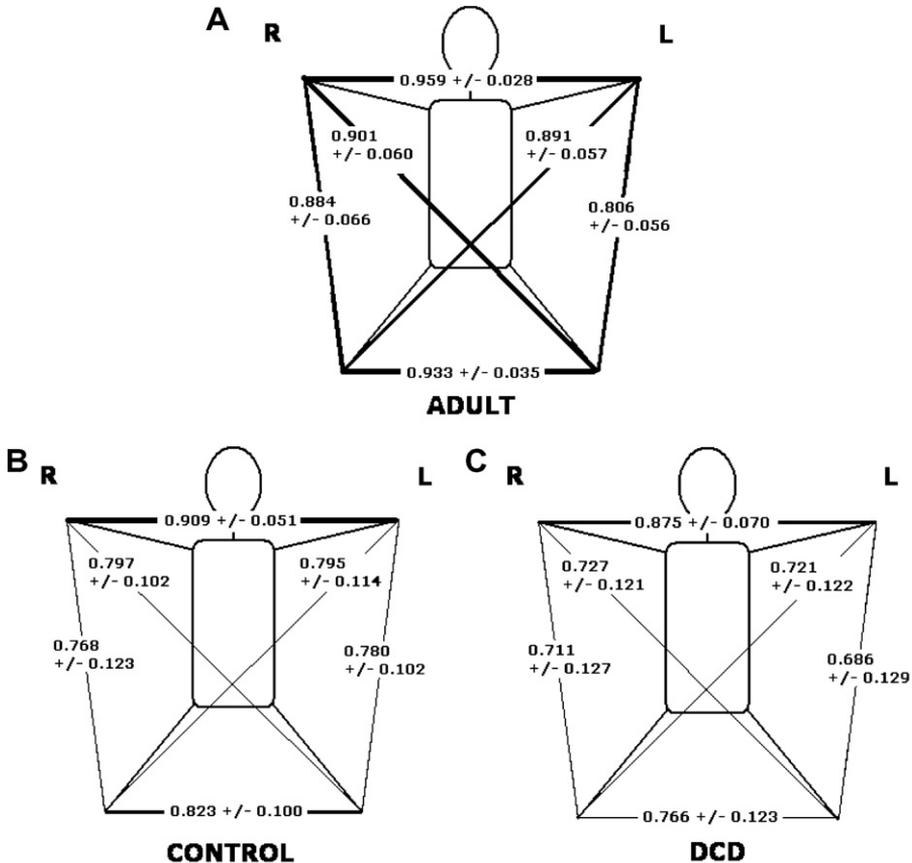

Fig. 4. Maximum coherence (group means + group SDs) for (A) adult group, (B) typically developing group and (C) DCD group. For each limb combination, the adult participants showed higher max coherence than the TD control participants, which in turn showed higher max coherence than the DCD participants. Coherence was greatest between homologous limb pairs (both arms or both legs) for all participants tested.

A

Approximate Entropy Right and Left Hands

B
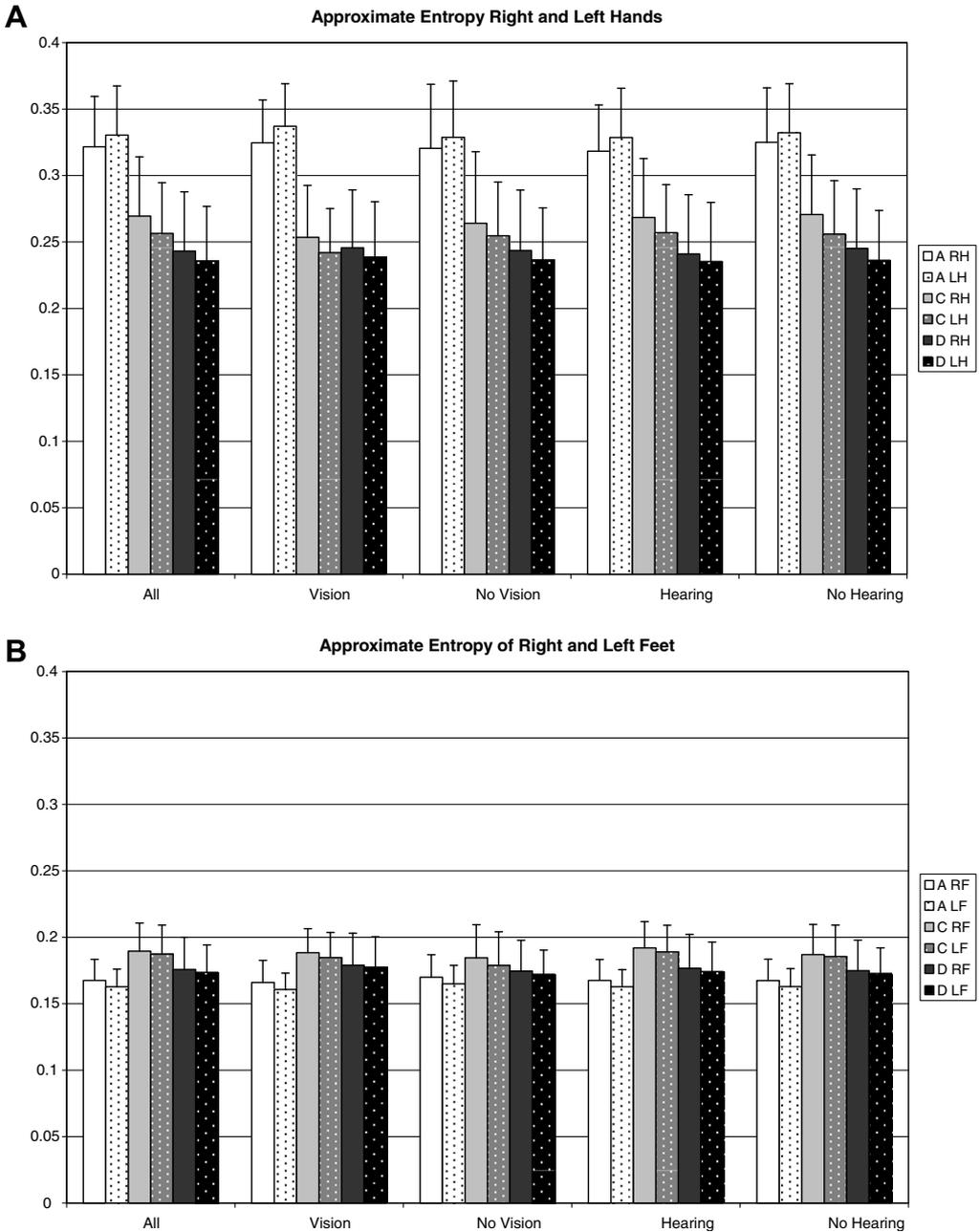

Approximate Entropy of Right and Left Feet

Fig. 5. Approximate entropy values for (A) hands and (B) feet. Those values closer to 0 represent less complexity. RH = right hand; LH = left hand; RF = right foot; LF = left foot. A = adult participants, C = typically developing children, D = children with DCD.

these combinations of limbs than the DCD children except for the left foot–right foot and left hand–right foot, which were not shown to differ.

3.4. Approximate entropy

Fig. 5a shows ApEn values for the left and right hand and Fig. 5b shows ApEn values for the left and right foot as a function of group for each condition. When interpreting ApEn, values range from 0 to 2, and those values closer to 0 represent less complexity (Stergiou, 2004). As depicted, all groups exhibited a high degree of regularity in both feet and hands during performance of the task (given the proximity of values close to 0), although the regularity of the feet is greater than that of the hands. Results of the statistical analyses of the ApEn analysis, which were performed for the feet and hands separately, showed significant differences as a function of group only for the right and left hands, $F(2, 108) = 14.07$, $p < .001$ and $F(2, 108) = 8.50$, $p < .001$, respectively. Tukey's HSD post hoc tests showed that ApEn values of the left and right hands of the adults were significantly greater in contrast to the DCD and control children, whereas those of the two children's groups did not differ significantly from each other.

4. Discussion

To determine the influence of available sources of sensory information on multi-limb coordination, we investigated sensorimotor interactions by measuring the degree of coordination between arms and legs under four different sensory availability conditions involving vision and hearing. There are two main results. First, although the DCD group was able to accomplish this complex task, there was significantly more within-individual and between-participant variability than either TD or adult groups in timing the claps with the footfalls, in timing each limb separately, and in the coherence analysis across pairs of limbs. The TD group was significantly different from the adults in coherence, but not for the between- or within-limb timing measures. Only the analysis of regularity and two pairs of coherence measures demonstrated any similarity between the DCD and TD groups. Second, the availability of vision and auditory feedback had no influence on the coordination of clapping/marching for any group or variable.

The predicted result of increased variability for this self-initiated multi-limb coordination task is consistent with our previous full-feedback and externally cued experiment where children with DCD were always more variable within and across trials than the adult group and more variable than their typically developing counterparts for the timing measures examined here (Whitall et al., 2006). Our current finding suggests the primary cause of the increased variability of performance in this multi-limb task is not the attempt to match an external cue, since the present data set demonstrates similar levels of temporal variability and differences between children and adults. That is, the mean variability of phasing (across four frequencies that bound the self-chosen ones here) was 6%, 12% and 18% for the adult, TD and DCD group respectively with statistical differences being between Adult/TD and DCD groups as they are in the present study.

We extend the common finding of increased variability in children with DCD by dissecting the nature of the variability in more detail. For example, adults demonstrated greater coherence than both groups, indicating that there is a developmental progression from stabilizing temporal events to stabilizing the coupling of frequencies between limbs. Moreover, the children with DCD were equally as stable as the TD children in foot–foot coherence. Perhaps because walking develops early and is used frequently, both groups have had sufficient experience to be equally stable although not adult-like. This implies

that there may be a threshold to the amount of practice that allows children with DCD to catch up with their peers. The fact that children with DCD did not differ from TD children on at least one other pairing (left hand–right foot) seems to support this notion. This argument would be in line with the hypothesis that children with DCD are delayed rather than developing atypically.

There was a similar correspondence between the children's groups when we looked at whether the variability within a trial for each limb reflects a simple, regular structure or a more complex pattern. The adult group appeared capable of producing a stable marching action, and then more flexibly coupling the clap action to the legs. In contrast, both groups of children performed upper extremity actions that were less adaptable and more rigid. This follows the previously hypothesized developmental progression in motor coordination as moving from loose to tight to flexible coupling (Thelen, 1986). Both groups of children displayed less complex structures in their arms over the times series, suggesting less flexible coupling in the face of changing demands. These ApEn findings reflect the results of the coherence analysis which also show no differences between the children's groups, in this case, regarding frequency association between diagonal couplings. For the adults, the frequency association among all limb pairs is high, which suggests that they were able to adjust to changes in frequency in one limb with changes in all other limbs. It will require a larger cross-sectional (or longitudinal) study to determine when TD children acquire this capability and to determine whether children with DCD ever do.

The second major finding, regarding sensory withdrawal, did not support our initial hypothesis since there were no effects of sensory input removal in this protocol. If multiple sources of sensory information are typically mapped to create an internal model of the sensorimotor relationships then our results suggest that the sensory information removed was not essential for production of this particular coordinated action. From her perspective of a dynamic systems approach to the development of action, Thelen (e.g., Thelen & Smith, 1994) argued that development of specific behaviors emerges a posteriori through local processes that operate in a particular context. Although this approach assumes that there may be multiple contributing systems for a specific behavior this does not imply that all potentially feasible contributing systems are ipso facto important contributors. Clearly, for the particular multi-limb coordination task we set for our participants, vision and audition are not contributing systems to the maintenance of the behavior. Plausible reasons for this lack of contribution can be hypothesized through an analysis of the multi-limb task first with respect to vision and then internal audition.

If we consider the leg task first, the act of marching (walking) in place consists of well practiced alternating movements that almost certainly have a well-learned representation or internal model. In fact, it would be problematic if we did not have an internal model in place as it would preclude walking in the dark. Thus, it is not surprising that vision is not necessary to accomplish this particular task. On the other hand, we had assumed that the arm task, clapping, might need some visual information given that it is less well practiced on its own, let alone as a multi-limb coordination task. Nevertheless, the mirror-movement simplicity of clapping allows children as young as 4 years of age to accomplish this task with adult-like characteristics (if not accuracy) (Fitzpatrick, Schmidt, & Lockman, 1996). Thus, it follows that our participants probably had a reliable internal model of how to bring the arms together for clapping. However, it is important to note that we did not measure the spatial accuracy of the cymbals clashing, so we cannot comment on whether the spatial variability of the hand movements was also high, though presum-

ably the margin of error was large enough not to require visual information for guidance on clapping.

The lack of effect when the intrinsic sounds of the cymbal and feet were eliminated was more surprising. We made the assumption that participants might use this information to keep the claps/footfalls more rhythmic (evenly spaced between the feet and in synchrony with the clap). However, neither the act of spontaneously walking or hand clapping demands the use of external auditory cues. Thus one can assume that these behaviors are built up as internal models, presumably with the use of other (internal) sensory mechanisms such as proprioception and cutaneous information as guiding information. Thus, even when we forced attention on timing and used a cymbal to enhance the sound, the adults and TD children either did not use the available auditory information or their performance was already maximized. Our hypothesis that children with DCD might spontaneously use the available auditory information to assist their performance was based on an assumption that they would perceive their own instability and use the available auditory information to improve their stability. It is impossible to know whether, in fact, they did not try or were unable to use the information. Since their temporal variability was similar to a study where external cues were used, it seems likely that even if they did try to use the information it would not be useful to them. Resolution of this issue will require further study.

5. Conclusions

In conclusion, children with DCD are able to accomplish the basic gross-motor coordination task of coordinating their clapping to their footfalls while marching in place, but they do so with increased variability which is particularly associated with their arm movements. However, coherence analysis of the two legs and the approximate entropy analysis did not distinguish the two children's groups. The availability of vision and hearing did not play a significant role in stabilizing temporal coordination of this task, indicating that proprioceptive and cutaneous cues must play a larger role in accomplishing the coordination and accurate phasing of the upper and lower limbs for this particular multi-limb task.

Acknowledgements

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