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Continuous and Discontinuous Drawing: High Temporal Variability Exists Only in Discontinuous Circling in Young Children

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Abstract

The authors studied whether the drawing variability in young children is best explicable by (a) demands on the explicit timing system, (b) an underdeveloped ability to control limb dynamics, or (c) both. The explicit timing demands were lower in continuous drawing in comparison with the discontinuous task. The authors manipulated limb dynamics by changing the number of joints involved, with line drawing requiring fewer joints than circle drawing. Results showed that young children had high temporal variability in discontinuous circling but not in other conditions. The authors argue that both explicit timing and dynamic complexity of limb control may be determinants of temporal consistency and may thus play an important role in the development of drawing and writing skills in children.

Keywords

cerebellum; circle drawing; dynamic control; timing

Proficiency in writing is one of the most important developmental achievements during the preschool and early school years. Children first attempt to draw by spontaneous scribbling at approximately 15 months of age (Kellogg, 1969). By the age of 2 years, children can crudely draw circular, vertical, and horizontal lines that follow the appropriate directions (Knobloch & Pasamanick, 1974); however, the quality of performance varies considerably. It is not until the late elementary school years that consistent drawing and writing patterns emerge (Hamstra-Bletz & Blote, 1990). In particular, studies have shown that the regularity of movement speed and the smoothness of the children's handwriting improves from grade 2 to grade 6 (Hamstra-Bletz & Blote, 1990, 1993). In addition, Wann, Wing, and Sovik (1991) reported that children across these grades have more difficulty in performing discontinuous loops, as in *garlands* (e.g., the letter *u*) and *arcades* (e.g., the letter *n*), than continuous loops (e.g., the letter *l*). The discontinuous garlands and arcades show much higher irregularity and inconsistent movement times in comparison with continuous loops (Wann et al.). Similarly, Thomassen and Teulings (1983), who were interested in the constancy of stationary and progressive handwriting, reported that 7-year-old children wrote continuous loops (e.g., the letter *e*) better than they did

waves (e.g., the letter *w*) and sawtooth-like shapes (multiple “U” shapes). Continuous loops showed less timing irregularity in comparison with others. Taken together, these behavioral findings led us to question why children show more temporal difficulties in the discontinuous writing patterns than in the continuous writing patterns.

Recently, Spencer, Zelaznik, Diedrichsen, and Ivry (2003) proposed that there are separate timing mechanisms controlling the temporal consistency in continuous drawing movements versus discontinuous drawing movements. Producing discontinuous movements requires an explicit representation of the temporal goal (i.e., when to start and stop), whereas making continuous movement does not need an event-related explicit timing process. Support for this claim can be found in the behavioral studies of patients with cerebellar lesions (Spencer et al., 2003; Spencer, Zelaznik, Ivry, & Diedrichsen, 2002). Patients with cerebellar damage have deficits in performing fast circle-drawing movements. These deficits are restricted to discontinuous movements, which require initiation and termination for each circle during drawing. However, these patients appear to be without any problems regarding temporal variability when producing the continuous, rhythmic movements (Spencer et al., 2003; Spencer et al., 2002). On the basis of these findings, Spencer et al. (2003) proposed that timing emerged from the continuous drawing trajectory and is thus an implicit timing process. However, discontinuous drawing requires an explicit timing process that times the occurrence of specific events; this latter process involves the cerebellum.

Similarities in the behavioral difficulties with discontinuous movements in patients with cerebellar lesions and those of typically developing young children suggest that developing brain function in childhood may play a role in changes observed in the temporal consistency of children's drawing and writing movements. Anderson (2003) showed that in humans, the cerebellum develops slower and over a longer duration than do most of the other brain areas. A longitudinal magnetic resonance imaging (MRI) study of 259 children showed that the cerebellum volume matures later than other brain areas, peaking at approximately the age of 19 years, in comparison with a peak in total cerebral volume at approximately the age of 16 years (Giedd et al., 1996). These anatomical studies have indicated the possibility that cerebellar function is not fully developed during childhood. Support for the role of the cerebellum in motor skill development can also be found in animal studies. For example, undernutrition during the brain growth spurt period in rats leads to a smaller cerebellum containing less neuronal and glial cells, less synapses, and decreased myelination in comparison with other parts of the brain that are less seriously affected (Gramsbergen & Westerga, 1992). Behaviorally, these rats had a retarded and prolonged transition from immature locomotion and showed signs of long-lasting clumsiness. Similarly, dexamethasone injected into young rats during the maturational stage of the cerebellum induced long-lasting abnormalities in walking development including postural tremor and clumsiness (Gramsbergen & Mulder, 1998).

Coordination and fine-tuning of fast and accurate movements are a major function of the cerebellum (Thach, 1998). If the slow development of the cerebellum limits the rate of the development of children's handwriting, difficulties with timing—particularly explicit timing (Spencer et al., 2002, Spencer et al., 2003)—might be at the root of the writing problems. At the same time, handwriting also involves complex limb dynamics that may be more difficult in discontinuous movements. Bastian, Zackowski, and Thach (2000) reported the requirement of turning certain muscle groups on and off in multijoint movements, such as those in discontinuous circle drawing, to be very challenging for patients with cerebellar lesions. Cerebellar patients can produce almost normal single-jointed movements but have problems with multiple-jointed movements (Bastian et al., 2000). In a recent study, we found that cerebellar patients showed higher temporal and spatial variability in discontinuous circling in comparison with continuous circling (Bo, Block, Clark, & Bastian, 2005). However, both

modes of circling were more impaired than the age-matched controls indicating the existence of other control mechanisms underlying continuous and discontinuous movements besides explicit timing. In addition, previous developmental studies have indicated the possibility that kinematic and dynamic limb control are not yet well tuned in children; these findings also indicate the possibility of other control mechanisms (Contreras-Vidal, Bo, Boudreau, & Clark, 2005; Jansen-Osmann, Richter, Konczak, & Kalveram, 2002).

In the present study, we examined whether there are different developmental trends in children's continuous and discontinuous circle and line drawing. We investigated the developmental landscape over which a cross-sectional sample of children 5–10 years old performed these tasks. Experimentally, we manipulated the task's dynamic complexity by changing the number of joints involved. The line drawing task involved predominantly single-joint elbow movements, whereas circle drawing involved elbow and shoulder movements. The temporal demands were manipulated by asking participants to perform the drawing task continuously or discontinuously, with the discontinuous movements requiring more explicit temporal control.

Method

Participants

Participants were 30 typically developing children (16 boys, 14 girls) between the ages of 5 and 10 years (M age = 8.58 ± 1.51 years) with 5 children at each year of age. We included 5 college-age adults to provide a mature performance reference. Participants came from the area surrounding a suburban university community. All children were screened with the Movement Assessment Battery for Children (MABC; Henderson & Sugden, 1992) and the Beery–Buktenica Developmental Test of Visual-Motor Integration (4th edition; VMI; Beery, 1997). The inclusion criteria for child participants were (a) a standardized VMI score between 2 SD s above and 1.5 SD s below the mean and (b) a MABC score higher than the 30th percentile. Handedness was determined by using the MABC criteria. Children's parents or legal guardians were fully informed of the task purpose and signed the consent forms prior to the child's participation in the study. Adult participants provided their consent before the experiment started. All procedures were approved by the Institutional Review Board of the University of Maryland, College Park.

Apparatus

Participants sat comfortably at a table with a digitizing pen taped on the index finger of the dominant hand (i.e., the hand used for handwriting). We adjusted the height of the chair so that the participant's hand could move freely in the horizontal plane and the lower end of the sternum touched the tabletop throughout the experiment. A digitizing tablet (WACOM InTuos™, Vancouver, Canada) was placed on the table and centered at the participant's midline in front of the chest so that participant could look directly at the hand and a template during the whole experiment. The tablet was used to collect data on the pen position in the x – y coordinates at 200-Hz sampling rate by using custom software written in OASIS™ (Kikosoft, Nijmegen, Netherlands). Because the pen was taped on the child's finger, the pen position read from the tablet represented the child's finger movement. A paper template, either a circle or a 45° slanted thin ellipse (resembling an up-and-down line movement), was placed at the center of the tablet. The diameter of the circle template was 5 cm, and the size of the ellipse template was 7.07 cm in the long axis and 0.2 cm in the short axis. We used the thin ellipse instead of a single line because it decreased young children's confusion about where to make pauses while the basic motion was still line drawing (see Figure 1). The participants were asked to move their finger over the template. We instructed participants to use the template as a guide rather than trying to strictly trace the circle or ellipse. The participants' movement trajectory was recorded on

the tablet when they moved their finger. Data were collected and stored on a computer for offline processing. Real-time visual feedback of the pen movements on the computer screen was available only for the experimenter during the experiment.

At the beginning of each trial for all conditions, we turned a metronome (Quikwatz) on to initiate the movement rhythm. The target cycle duration (the time to complete one circle or one thin ellipse) was fixed at 550 ms. A continuation paradigm was used (i.e., after approximately 10–15 beats when the participant had adjusted to the rhythm, the metronome was turned off, and the participants were required to move as consistently as possible for 20 s until the end of the trial).

Procedure

Before any test started, we fully explained the purposes and procedures to both parents and participants with appropriate language. All the children were assessed by the screening tests before the drawing tests.

Screening Tests

All screening tests took place in a quiet testing area. First, we administered the MABC to identify children who had movement difficulties. Second, after a 5-min break, we administered the VMI to evaluate the fine motor skill level of the children. If a child did not qualify as a typically developing participant, he or she was excluded from the drawing tests.

Drawing Experiment

We required the participants to perform drawing movements on a template using a digitizing pen taped on their index finger in four different conditions that we presented in random order. The experimenter explained and demonstrated the movement before each condition. The participants had several trials to become familiar with the task before formal testing began. When the experimenter said, “Ready, go,” a formal trial started. The metronome was turned on, and the participants synchronized their movements with the metronome. Once the experimenter had observed the participant and believed that the participant had become synchronized with the rhythm at approximately 10–15 beats, the metronome was turned off. All participants were asked to move as consistently as possible for 20 s until the experimenter said, “Stop.” If the participants could not get the rhythm within the first 15 beats, the trial was restarted. The instructions emphasized temporal consistency instead of spatial accuracy throughout the tests. The experimenter emphasized the instructions between trials but not during the trials. After one or two trials, the experimenter gave positive feedback to encourage the participant to keep up the performance. There were five trials in each condition. We grouped trials by condition into blocks, and we randomized block order across participants.

Condition 1: Continuous circle drawing—We asked the participants to start each trial with the pen tip on the top of the circle template. They were then required to make continuous counter-clockwise movements, trying to be at the top of the circle with each metronome beat. Their wrist and fingers were not constrained, allowing for multijoint movements involving elbow and shoulder.

Condition 2: Discontinuous circle drawing—We asked the participants to start each trial with the pen tip on the top of the circle template. They then made one counterclockwise circle, stopped at the top of the circle, omitted one beat (550 ms), and then performed the next circle movement. These discontinuous movements also required multijoint movements including elbow and shoulder.

Condition 3: Continuous line drawing—The participants started the trial at the upper end of the ellipse template and tried to be at the upper end of the ellipse coinciding with the beat of the metronome while moving back and forth between the two turning points continuously at 550 ms per up-and-down motion. Because of the thin short axis of the ellipse, the movement was basically a line-drawing motion. To control the number of joints involved, we had the participants wear a splint to keep the wrist and fingers rigid. The position of the elbow was supported so that the back-and-forth movements pivoted around the elbow only.

Condition 4: Discontinuous line drawing—We asked the participants to first draw a back-and-forth line on the thin ellipse template for each interval formed by two beats and then to omit one interval before the next back-and-forth movement. They were required to initiate and stop one movement cycle (i.e., discontinuous line drawing) at the upper end of the template simultaneously with the beat of the metronome. The duration for drawing one back-and-forth line and the duration for pausing were one beat interval at 550 ms. The participants wore a splint to constrain the number of joints involved. The position of the elbow was supported so that the back-and-forth movements were controlled by the single-joint elbow motion.

The entire experiment including the screening tests lasted approximately 90 min. The children were given short breaks between trials and conditions.

Data Analysis

We filtered the time series representing the x - y position of the pen movement by using an 8th-order dual-pass Butter-worth filter cut-off frequency = 10 Hz. Customized MATLAB scripts from our lab were used to mark each movement segment (onset and offset; i.e., one cycle or one up-and-down line) on the basis of the following criteria: For the continuous circle drawing, the onset and offset of each movement segment were marked when the position in the y axis was positive and the position in the x axis passed zero (equivalent to the top of the circle template). For the continuous line drawing the starting and ending of each segment were marked when the positions in both x and y axes were positive and close to the top end of the ellipse. In discontinuous circle and line drawings the tangential pen velocity was first obtained from the position data. The program searched the velocity time series, marked the starting points for each movement segment when the velocity exceeded 5% of the maximum peak velocity, and marked the offset for each segment when the velocity dropped lower than 5% of the peak velocity. On the basis of these criteria, the experimenter visually inspected the data to verify that the identified starting and ending points for each segment were appropriate. In a few cases in which the algorithm failed to mark the onset or offset, the experimenter manually adjusted the markers. Once all the segments were verified, the dependent variables were calculated.

Dependent Variables

We defined *movement time* (MT; in seconds) as the time taken for completion of one segment. In other words, it is the time of completion of one circle or one back-and-forth line. *Movement time coefficient of variation* (CVMT; without unit) was calculated by dividing SD MT by M MT and then multiplying by 100 to measure the temporal variability of the movements.

Movement total distance (TD; cm) was the total movement length traveled by the pen for each individual segment (i.e., one circle or one back-and-forth line).

We calculated *total distance coefficient of variation* (CVTD; without unit) by dividing SD TD by M TD and then multiplying by 100 to measure the spatial variability of the movements.

Root mean square error (RMSE; in centimeters) was the average point-to-point deviation of the actual movement trajectory from the ideal trajectory (i.e., the circle or ellipse based on the templates; Contreras-Vidal & Buch, 2003). We resampled the data points so that both the actual trajectories and the ideal trajectories were represented by N data points sampled at equal distances within each trajectory. The ideal trajectories were verified by the experimenter who traced the templates carefully before the testing sessions. The trajectories were as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N [(x_{ai} - x_i)^2 + (y_{ai} - y_i)^2]}{N}}$$

where (x_i, y_i) and (x_{ai}, y_{ai}) were corresponding points of the resampled trajectory and the ideal trajectory (template), respectively, and N is the number of points in the path.

Statistical Analysis

We used a mixed model linear regression analysis for all dependent variables, MT, CVMT, RMSE, TD, and CVTD. We treated age as a continuous variable and treated continuity (continuous vs. discontinuous) and shape (circle vs. line) as categorical variables. The variance and covariance structures were adjusted because the later two independent variables were repeated measures. The interactions in temporal variability (CVMT) are of particular pertinence to this study.

Results

Overall, all children were able to successfully perform the task, although their performances differed across the age groups. Figure 1 shows exemplars in each the age group (children 5–10 years old and adults during the continuous, discontinuous circle, and line-drawing tasks). As we expected, older children showed more consistent trajectories over repetitive drawings, whereas the younger group showed more variable responses in all conditions.

Because researcher have considered cerebellar timing as operating in the range of a hundred to hundreds of milliseconds (e.g., Handy, Gazzaniga, & Ivry, 2003; Ivry & Richardson, 2002), we first observed how long it took for children to complete one cycle. Individual data (see Figure 2A) showed that the means for all children in all conditions were lower than 1 s (0.32–0.98 s), suggesting that all participants were moving within the cerebellar-timing range. Regression analysis revealed a significant main effect of shape for MT, $F(1, 112) = 5.70, p < .05$. The children tended to take a longer time in drawing circles compared with lines.

The ideal travel distances for completion of one circle and one up-and-down line are approximately 15 cm and 14 cm, respectively. The Continuity $\times$ Shape interaction, $F(1, 112) = 27.65, p < .01$, suggested that children were drawing longer paths in the continuous circles and discontinuous lines compared to the discontinuous circles and continuous lines (see Figure 2B).

The CVMT is the key measure for the present study because researchers (Spencer et al., 2003) think it reflects the temporal consistency in repetitive movements. All slope coefficients (regression slope by age for each condition) were significantly different from zero (all $ps < .05$), suggesting that the temporal variability decreased with increasing age in all four types of movements. For CVMT, there were significant interactions of Age $\times$ Continuity $\times$ Shape, $F(1, 112) = 8.80, p < .01$; Age $\times$ Continuity, $F(1, 112) = 8.19, p < .01$; Age $\times$ Shape, $F(1, 112) = 10.98, p < .01$; and Continuity $\times$ Shape, $F(1, 112) = 8.09, p < .01$. The three-way interaction (see Figure 3) allowed us to run further slope comparisons across four combinations of continuity and shape (i.e., continuous circle, discontinuous circle, continuous line, and

discontinuous line). These revealed that the younger children showed much higher temporal variability in the discontinuous circling condition but not in the other three conditions (all $ps < .01$). The 5-year-olds dramatically decreased their temporal variability by 14% from the discontinuous circle drawing to the continuous circle drawing, whereas the 10-year-olds showed similar temporal variability between these two conditions. Contradictory to the explicit hypothesis, post hoc slope comparison did not show age-related differences between the continuous and discontinuous line drawings ($t = -0.25, p = .94$). Deviating from what the dynamic control hypothesis would predict, no difference was found between continuous circle drawing and the continuous and discontinuous line drawings ($ps = .81$ and $.74$, respectively). At this point, these results support a contribution of both explicit time and dynamic control rather than a sole proprietor role of either process.

We measured spatial variability in two ways: The RMSE represents the variability between the actual trajectory and the ideal movement (i.e., the template); the CVTD represents the variability among actual repetitive cycles. A mixed model regression analysis revealed significant main effects for shape, $F(1, 112) = 14.53, p < .01$, in RMSE. The circle drawings were more variable than the line drawings of all children, as measured by RMSE. The statistical results in CVTD were similar to those in CVMT. A significant Age $\times$ Continuity $\times$ Shape interaction, $F(1, 112) = 16.15, p < .01$ (see Figure 4) indicated that the younger children showed much higher spatial variability than did the older children in the discontinuous circling condition, but not in the other conditions (all $ps < .01$). The older children could maintain their spatial variability among four types of movements, whereas the 5-year-olds decreased their spatial variability either by moving in continuous circles (improvement by 10 units) or by drawing lines (improvement by 7 units). No slope differences were found between continuous circle drawing and line drawing ($p = .41$), between continuous circle drawing and discontinuous line drawing ($p = .56$), and between discontinuous line drawing and continuous line drawing ($p = .86$).

Discussion

In the present study, we investigated whether the drawing variability in young children was best explicable by demands on the explicit timing system, by an underdeveloped ability to control limb dynamics, or by both. We varied the explicit timing demands by asking children to perform discontinuous movements versus continuous movements. Dynamics demands on the control system were manipulated by changing the number of joints involved in line drawing compared to circle drawing. On the basis of the explicit timing hypothesis, we expected that the young children would show higher temporal variability and spatial variability in the two types of discontinuous drawing, regardless of whether they were drawing circles or lines. Based on the dynamic control hypothesis, we predicted that young children would be more variable when drawing circles than when drawing lines. Partially consistent with each of the predictions, our results indicate that higher variability existed only in the discontinuous circling condition but not in the other conditions. It appears that the development of limb dynamic control and that of explicit timing are both major players in explaining the developmental changes in children's drawing behavior.

A number of developmental researchers of handwriting have extensively described the temporal inconsistency in young children during early school years (Hamstra-Bletz & Blöte, 1990, 1993). Temporal irregularity appears to be even worse when children perform discontinuous writing patterns (Thomassen & Teulings, 1983; Wann et al., 1991). Although such phenomena have been observed for decades (e.g., Wann et al., 1991), the underlying mechanisms are still not clear. For quite a long time, temporal control has been considered one of the major functions of the cerebellum (e.g., Ivry, Keele, & Diener, 1988; Lamarre & Mercier, 1971), a brain structure that develops more slowly and over a longer duration than do most of

the other brain areas (Anderson, 2003). Recent findings in patients with cerebellar lesion (Spencer et al., 2003) further pointed out the explicit timing mechanisms in controlling discontinuous drawing movements. In the present study, young children showed more difficulties in discontinuous circling, indicating that explicit timing may be one of the determinants of temporal consistency, although other mechanisms may be involved.

Our finding that young children improved their performance in the discontinuous line drawing compared with the discontinuous circle drawing raises the possibility of an explanation that is alternative to explicit timing: The dynamic demands for discontinuous movements are more complex than those of continuous ones. There are more acceleration–deceleration periods associated with starting and stopping a movement repeatedly in the discontinuous condition. This difference is a type of dynamic complexity that requires tight control over agonist and antagonist muscles to make the starts and stops appropriately. Hore, Wild, and Diener (1991) found that patients with cerebellar damage have more difficulty repetitively starting and stopping their movements even when they are making a single joint movement. In the present study, we simplified the limb dynamics of circle drawing by including line drawing in which the number of joints involved was reduced. If limb dynamics—in either removing the interaction torques or reducing the tight control over agonist and antagonist muscles—were playing an important role in drawing, we should expect different age-related trends across the four conditions, where the discontinuous circle drawing is the most challenging one and the continuous line drawing is the easiest. Again, our results partially pointed in this direction: Both the temporal and spatial variabilities were similar between the discontinuous line drawing and the continuous circle drawing and were much lower than those in the discontinuous circle drawing. Decreasing the complexity of the limb dynamics improved the children's performance substantially, suggesting that the development of dynamic control is one of major factors in controlling children's drawing behavior.

What is interesting here is that the temporal variability in the continuous line drawing was not better than that in either the continuous circle drawing or the discontinuous line drawing, and that finding contradicts both the explicit timing hypothesis and the dynamic control hypothesis. Recently, Dounskaia (2007) reported detailed joint kinematics between the line and circle drawings in adults, suggesting that continuous motion, regardless of whether it is along a circle or a line, requires similar sinusoidal motion of each participating joint. The difference between these two types of movements is that the joints accelerate and decelerate simultaneously during line drawing, whereas there is a constant phase offset between joint motions during circle drawing. Her findings imply that the limb kinematics between continuous circling and continuous and discontinuous line drawing are not substantially different from each other, because of the similar acceleration–deceleration patterns. In contrast, discontinuous circle drawing requires termination of motion at both joints simultaneously, a kinematic state that never occurs during continuous drawing. To achieve the state of motion termination before the next cycle, the individual needs to perform additional limb acceleration–deceleration. Unfortunately, in the present study, we only measured the endpoint trajectory. Without kinematic data from other joints, it is difficult to directly apply the results from the adults to the young children. In fact, a number of developmental studies have reported that children's kinematic and dynamic controls are not fully developed in early childhood (Contreras-Vidal et al., 2005; Ferrel, Bard, & Fleury, 2001; Jansen-Osmann et al., 2002). In this context, it is possible that the less-tuned internal representation of limb dynamics and kinematics plays an important role in controlling the drawing and writing movements of children.

Taken together, the present results do not exclude possible influence on performance of the two factors, explicit timing and limb dynamics. Other factors, such as complexity of joint kinematics during discontinuous circle drawing, may also be influential. The increased variability that researchers observed during discontinuous circle drawing in young children

has also been found in cerebellar patients, supporting the hypothesis that the performance variability in children may be related to a cerebellum that has not fully developed.

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FIGURE 1. Exemplar movement paths for the continuous circle, discontinuous circle, continuous line, and discontinuous line drawing from 1 participant for each age group. The scale is in centimeters.

FIGURE 2.

(A) Age regression for movement time (MT) and (B) mean movement distance (TD) in continuous and discontinuous circle and line drawings. The triangles together with the solid line show the individual measures and linear age regression for the continuous circling (slope = -0.026 , -0.630 for MT and TD, respectively). The solid dots with the dotted line represent the individual measure and the linear regression for the discontinuous circling (slope = -0.023 , -0.285 for MT and TD, respectively). The circles together with the dotted line show the individual measure and the linear regression for the continuous line drawing (slope = -0.004 , -0.092 for MT and TD, respectively), whereas the squares with the dotted line represent the individual measure and the linear regression for the discontinuous line drawing (slope = -0.012 , -0.655 for MT and TD, respectively).

FIGURE 3.

Age regression for coefficient of variation of movement time (CVMT). The triangles together with the solid line show the individual measures and linear age regression for the continuous circling. The solid dots with the dotted line represent the individual measure and the linear regression for the discontinuous. The circles together with the dotted line show the individual measure and the linear regression for the continuous line drawing, whereas the squares with the dotted line represent the individual measure and the linear regression for the discontinuous line drawing. Slopes are -1.080 , -3.645 , -0.927 , and -0.881 for continuous circling, discontinuous circling, continuous line, and discontinuous line drawing conditions, respectively.

FIGURE 4.

Age regression for coefficient of variation of movement distance (CVTD). The triangles together with the solid line show the individual measures and linear age regression for the continuous circling. The solid dots with the dotted line represent the individual measure and the linear regression for the discontinuous. The circles together with the dotted line show the individual measure and the linear regression for the continuous line drawing, whereas the squares with the dotted line represent the individual measure and the linear regression for the discontinuous line drawing. Slopes are -0.019 , -2.787 , -0.396 , and -0.309 for continuous circling, discontinuous circling, continuous line, and discontinuous line drawing conditions in CVTD, respectively.