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Training To Improve Manual Control In 7–8 And 10–12 Year Old Children: Training Eliminates Performance Differences Between Ages

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Abstract

Many children have difficulty producing movements well enough to improve in perceptuo-motor learning. We have developed a training method that supports active movement generation to allow improvement in a 3D tracing task requiring good compliance control. We previously tested 7–8 year old children who exhibited poor performance and performance differences before training. After training, performance was significantly improved and performance differences were eliminated. According to the Dynamic Systems Theory of development, appropriate support can enable younger children to acquire the ability to perform like older children. In the present study, we compared 7–8 and 10–12 year old school children and predicted that younger children would show reduced performance that was nonetheless amenable to training. Indeed, the pre-training performance of the 7–8 year olds was worse than that of the 10–12 year olds, but post-training performance was equally good for both groups. This was similar to previous results found using this training method for children with DCD and age-matched typically developing children. We also found in a previous study of 7–8 year old school children that training in the 3D tracing task transferred to a 2D drawing task. We now found similar transfer for the 10–12 year olds.

Keywords

Transfer of learning; Motor development; Kinematic analysis; Figure copying

Introduction

Motor learning has been described as a process that first requires the learner to produce a qualitative approximation to a movement to be learned, followed by quantitative

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improvement through repeated practice [1]. In general, it can be difficult for children to produce the initial approximation required for subsequent practice to yield effective perceptuo-motor learning. This is clearly seen in very early childhood and infancy (i.e. [2]) but is also evident later in childhood when skilled and targeted actions are considered i.e. the development of throwing (see [3], [4]). These difficulties are increased for children exhibiting developmental disabilities like Developmental Coordination Disorder that yield increased movement variability and less reliable control [5]. So, then, the issue becomes how to aid or train children to produce qualitatively appropriate movements so that quantitative improvements can be achieved.

A traditional approach used by teachers and movement therapists to overcome this problem is to model desired movement skills with the hope that the learner will approximate some form of the required skill and then improve with practice. Accordingly, for instance, the expert will move the limbs of the learner through a desired form of movement (called “active assist”). Similar robotic approaches to therapy have been developed to move the passive limbs of the learner through the to-be-acquired movements; in effect, these robotic approaches “replace” the therapist (for reviews, see [6], [7]). Generally, however, passive robotic approaches to therapy for adults have not been found to be effective [8] – [10]. Moreover, passive training of movements in healthy adult populations appears not to lead to robust learning (for examples, see [11] – [13]). Snapp-Childs et al. [13] tested a form of passive modeling in which adult participants tracked the movement to be learned haptically. They grasped a stylus and followed it as it was moved through the target movements by a robotic arm. This was found to yield no learning of the new movement task. Another group of participants performed the same movements in training that required those movements to be generated actively. The active group exhibited good learning. Snapp-Childs et al. [13] concluded that skilled perceptuo-motor control is best acquired when practice of movements includes active generation and perceptual guidance of the movement. This circumstance creates a problem for efforts to provide support for better motor learning. Support must be provided in a way that still requires the learner to generate and guide a new movement actively.

With this in mind, we developed a method to train children to perform better manual control [14]. The method supports movement while nevertheless requiring the child to perform active perceptuo-motor control. The intended application is improved drawing or handwriting movements. The training task is a 3D tracing task, one that is normally very challenging. The actor holds a stylus in the hand and uses it to push a bead around a complex 3D shaped wire path. The problem is that it is difficult to keep the stylus tip on the wire so we used the robotic arm to model a virtual spring that acted on the stylus so as to hold it onto the wire (giving the phenomenological impression of a ‘magnetic attraction’ between the stylus and the wire). In this way, we provided support for the actor that allows both good performance and active movement generation during practice. This enables the actor to acquire good compliance control gradually, because the best way to move along the wire in this situation is to move compliantly, that is, to relax and to allow the wire to guide the movement. The learner may start by moving with high postural stiffness but ends by moving with low stiffness and good compliance. This is intended to yield better drawing,

tracing or handwriting given transfer of the compliance control from the 3D tracing task to 2D tracing or drawing tasks.

Previously, we tested this method with 7–8 year old children diagnosed as having Developmental Coordination Disorder, comparing their learning and performance with age-matched typically developing children [14]. We selected children with DCD to test because these children have poor fine motor control and exhibit major difficulties performing drawing, tracing or handwriting [15–17]. At baseline, before the new method was used to train the children, we found that the children with DCD were indeed significantly worse at the task than the age-matched typically developing children. The training regimen entails gradual reduction of the supporting ‘magnetic attraction’ as the performance improves. This was designed to maintain good self-efficacy during training. After training, the children with DCD performed as well, without any support, as the typically developing children who had also trained. In short, the method was found to be quite successful.

Next, we tested the method with typically developing 7–8 year old school children and included a test of transfer to a drawing task [18]. We also first tested the children using the Beery VMI, a standardized test intended to measure manual fine motor control. The Beery includes three different tasks each yielding a different score: a copying task yields a Visual-Motor Integration (VMI) score, a tracing task yields a Motor Control (MC) score, and a visual discrimination task yields a Visual Perception (VP) score. When the typically developing school children performed the 3D tracing task before training, we found that the level of performance varied as a function of the VP score of the Beery. Children with lower VP scores took longer to complete the 3D tracing task. All of the children improved their 3D tracing performance with training. Furthermore, the differences in performance at baseline predicted by the Beery VP score were eliminated. At post-training, the children performed the 3D tracing task equally well and significantly better than before training. The children also performed a copying task both before and after training at the 3D tracing task. They drew different wave-shaped figures and there was a tendency to make the copies too big. We found a direct relationship between the amount by which the copy was too large and the amount of error in reproducing the shape. We also found a relation between the Beery VP score and drawing performance. With lower VP scores, the drawn figures showed greater scaling errors and the shape error was lower. Finally, as a result of the training in the 3D tracing task, the children improved significantly in the accuracy of the drawn copies.

Present study

The purpose of this study was to examine and compare the efficacy of our training with children of different ages, now testing children older than previously tested and comparing the younger and older children. Thus far, the testing of the training method had been performed with children 7–8 years of age (both typically developing children and those with DCD). In the current study, we tested typically developing older children 10–12 years of age and compared their learning and performance on the 3D tracing task with that of the typically developing 7–8 year olds trained and tested previously. We also examined if the training positively transferred to a 2D figure copying (drawing) task as we previously found with 7–8 year old children. The testing of older children in comparison to the younger

children previously tested was motivated both by clinical relevance and Dynamical Systems theory.

The clinical problem is that children with mild to moderate motor impairments are frequently not identified as having impairments until 7–8 years of age; and, unfortunately, due to high demand for clinical services (i.e. see [19 – 21]) many of these children will remain untreated for long periods of time. Thus, many children are being treated for motor impairments at older ages than what one might hope. It is important to test the extent to which older children respond to therapeutic training as well as to test this in comparison to the response of younger children to better evaluate the effect of age differences.

Given this, how might older children be expected to perform relative to younger children before training and what might the training be expected to achieve in respect to children of different ages? Typically, older children outperform younger children on fine motor tasks. So, we predicted that older children would perform better than younger children before training. However, it is commonly assumed that this superiority is due to the maturational status of the nervous system. In turn, this suggests that age dependent performance differences are just that, age dependent and thus, not alterable by experience or training. However, the Dynamical Systems perspective outlined by Thelen and Smith [22], describes behavioral patterns as *self-organized* and *emergent*, existing and changing in response to a variety of cooperative and interacting factors. Specifically, behaviors arise as a result of characteristics of the individual (neurological status, state of arousal, motivation, body size and proportion, motor capabilities, etc.) that interact with constraints that are placed on the individual by the environment and task [23]. Thus, a specific level of motor performance reflects a number of interacting constraints so that, with support that alters those constraints, a child can achieve more advanced performance. On the other hand, the acquisition of motor skills (e.g. walking) has been shown to require experience and practice once the child is able to perform stably enough to be able to engage in practice [24]. Extrinsic sources of support can provide this requisite level of stability (e.g. in the case of walking, a walker, a maternal hand, or appropriately sized and configured furniture used to “cruise”). The support stabilizes the behavior so that it can be actively generated and performed in practice.

Our training method was designed to provide support that stabilizes performance of the manual tracing task to enable children to be able to learn to control the compliance of their hand/arm. The method entails progressive reduction in the level of support as performance improves. The goal was to maintain good self-efficacy during training. Because this modulation of support during training is tuned to the level of performance as performance changes, it can be expected to take levels of performance that are initially quite different to comparable levels of improved performance. Thus, differences in performance initially occurring as a function of age may well be expected to be eliminated by the training method.

We expected that, before training, the older children would exhibit superior performance than the younger children. Nevertheless, like the younger children, the older children were expected to improve in the training task. After training, we expected that both younger and older children might perform at a similar level of mastery on the 3D tracing tasks. If the main challenge to achieving superior performance is the ability to achieve sufficient stability

in the basic task so as then to be able to engage in useful practice to achieve quantitative improvements in performance, then similar levels of performance might be achieved with practice enabled by appropriate stabilizing support. Stabilizing actively controlled performance is what this new method of training was designed to achieve. Then, with performance improvements enabled by the training method, we further expected the older children to exhibit transfer of improvement in the 3D tracing task to a 2D figure copying (drawing) task as did the younger children in our previous work [18].

Methods

Participants

Twenty-two, 10–12 year old, children (10 female, 12 male) were recruited from the 5th and 6th grades at two local private schools. Nineteen of the children were right-handed and three were left-handed. There were 23 children (8 female, 15 male) in the previous study of 7–8 year olds [18]. They were recruited from the 2nd grade at a local public elementary school (this was a different school from the current data collection sites). All of those children, save one, were right handed.

Ethics Statement

This study was approved by the Indiana University Institutional Review Board. The children participated with informed assent with (written) informed consent from their parents/guardians.

Procedure and Apparatus

Before testing began, the parents/guardians evaluated their child using the Developmental Coordination Disorder Questionnaire (DCD-Q '07) [25]. These were completed by the parents/guardians at home. The children were tested in all sessions at their school. During the first session, all participants were tested using the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery). The participants also completed a 3D tracing task as well as a drawing task. A battery of three CKAT tasks (tracking, aiming, and tracing) was also performed [26]. In a number of subsequent sessions, participants completed a customized perceptuo-motor training program. After training, participants repeated the 3D tracing, drawing and CKAT tasks.

DCD-Q—This is a short parent questionnaire that aids in screening for motor impairments. This was included so that we could identify any children who were at risk of having a coordination disorder.

Beery—There are three components of the Beery: tests of 1) visual-motor integration (VMI), 2) visual-perception (VP), and 3) motor coordination (MC). The Beery VMI consists of 24 items (geometric forms) that are to be copied with pencil and paper. The VP and MC use the same geometric forms as the VMI, but the goals are different. In the VP, the goal is to choose one form, from a few slightly different alternatives, that is exactly the same as the stimulus. The alternatives can be very slightly different in form or size. In the MC, the goal is to trace inside (double) lines that define the stimulus forms.

Drawing—In the drawing test, participants were seated at a table in front of a tablet PC (Toshiba Portégé M750 tablet PC, screen size 163 mm by 260 mm, using CKAT software to manage stimulus presentation, user interface, and data collection as described by Culmer and collaborators [26]). The task was to view a form, then to copy (not trace) the form on the computer screen using a handheld stylus in the dominant hand. When a trial started, the upper half of the screen contained a black rectangular frame (12×6.5 cm) around a black line form and the lower half of the screen contained a green rectangle of equal dimensions to the black frame.

Participants looked at the form inside the black frame then placed the hand held stylus on the green rectangle at the location where they would start copying the form. (See [18] for illustration.) Once the stylus was inside the rectangle for 200 ms, the green rectangle disappeared and was replaced with a white rectangle (same color as the background) with a black border around it – similar to the rectangle in the upper portion of the screen containing the form to be copied. Once participants began to draw the form, an “OK” button appeared in the upper right-hand corner of the screen. When participants finished copying the form, they tapped this button with the stylus, completing the current trial and beginning the next one.

Participants performed three practice trials (a horizontal line segment, one cycle of a sine wave, and a circle) that were not analyzed, to become familiar with the task and interface. Then, participants completed two repetitions of each of nine forms (shown in Figure 1), for a total of eighteen trials. The forms were of three basic types with three examples of each type. The first type was simple, a circle, a square and a triangle. The second type was spiral, a circular, a square and a triangular spiral. The third type was wave. Each wave consisted of three sinusoidal cycles. The first was of constant amplitude with a height of 46 mm. In the second, the amplitude varied over the cycles in respect to the top of each cycle, but not the bottom where each cycle touched the baseline. The heights were 16, 46, and 16 mm. The third was similar to the second but the small amplitude cycles were centered vertically. Both the tops and bottoms of each cycle varied.

CKAT tasks—These tasks were the same as described in Flatters et al. [22].

3D tracing—The 3D tracing task was similar to that described and used in three previous studies [13], [14], [18]. In this task, participants performed variations of the same three-dimensional tracing task while seated at a table. The basic task was to push a brightly colored fish along a visible curved path viewed on a computer screen from a starting location (a plain square) to a finishing point (a checkered square) while racing a competitor fish. The participants grasped a stylus that was attached to a desktop force feedback haptic virtual reality device (PHANTOM Omni from Sensable Technologies) (shown in Figure 2a) and used the stylus to feel the wire path and push the fish.

The PHANTOM is an impedance control device where the user moves the stylus and the device reacts with a force if a virtual object is encountered. Thus, the PHANTOM has displacement as an input and force as an output. The mass and friction of the PHANTOM has been made small by careful mechanical design. In this experiment, participants could

“feel” the 3D path once they encountered it. Phenomenologically, it was as if the stylus was “magnetically attracted” to the path. The force pulling the stylus was modeled as a virtual spring where the stiffness of the spring could be altered. The spring had a virtual length of $\approx 0.5\text{cm}$ from the center of the path so the force dropped to zero if the stylus moved $>0.5\text{cm}$ from the path. The spring stiffness (and consequently the level of “attraction” or support) was parametrically varied to alter task difficulty. The forces pulling the stylus towards the spring were set at six different levels corresponding to forces of approximately 2.02N, 1.08N, 0.83N, 0.57N, 0.35N and 0.13N.

The curved paths were similar to a toy, commonly found in pediatrician waiting rooms, consisting of brightly colored curved ‘roller coaster’ wires with beads on them that can be pushed along the wires by a child. Using a stylus to push the bead along the wire would be, and is for our task, very difficult because the stylus tends to come off the path. Hence, for our task, the path ‘magnetically attracted’ the stylus to hold it on the path. The ‘magnetic strength’ was parametrically varied, as described above, to alter task difficulty. At Baseline and Post-Training, participants attempted two trials at each of eight levels of support (‘magnetic attraction’), on the path pictured in Figure 2, while racing a competitor fish that took 20s to travel the path from start to finish. From earlier studies, it was clear that most children would spend a very long time to complete a path and would become very frustrated with the lack of progress. So, each trial was terminated if a child could not complete more than one half of the path within 60s.

The training program consisted of up to five 20-minute training sessions that were separated by at least one week. During the training sessions, participants performed a series of 3D tracing tasks that were very similar to those in the Baseline/Post-Training sessions, but varied in length, curvature, and torsion (see Figure 2b, c, d). During training, participants raced against two different competitors; one competitor completed the path in 30s while the other completed the path in 10s. The first training session started with the highest level of support (‘magnetic attraction’), slowest competitor, and shortest path. The goal of the training was to allow the children to progress at their own pace through the different combinations of levels of attraction, paths, and competitors, so we used a “two-wins-in-a-row” rule to determine when the children progressed. After the participant “beat” the slowest competitor two times-in-a-row they progressed to the faster competitor. Once the participant beat both competitors they then moved to the next longest path with slowest competitor. After all paths and competitors were “beaten”, the level of support was decreased and the participant re-started with the shortest path and slowest competitor.

Data analysis

DCD-Q—The scores reported here are the raw scores from the DCD-Q.

Beery—The scores reported here are the norm-referenced percentile scores for the VMI, VP and MC components.

Drawing—The two-dimensional coordinates of the stylus were recorded at 120 Hz. These data were filtered using a dual-pass, second order Butterworth filter with a 10 Hz cut-off frequency. We calculated three variables for each of the forms that participants produced:

the scale factor, rotation, and shape error (this was previously referred to as ‘shape accuracy’ [26]). See [18] for illustration. To do this, we used a technique called ‘point-set registration’. In this technique, point-sets were generated for the participant-generated paths and reference paths by resampling the spatial coordinates, using linear interpolation, at a resolution of 1 mm. We then used a robust point-registration method [18] to determine the transformation that makes the participant-generated path most closely match the reference path. The transformation consisted of translation, rotation and isotropic scaling components. Scale factor is the isotropic scaling component of the transformation; that is, scale factor is how much growing or shrinking is required to make the participant-generated paths best match the size of the reference paths i.e. an oversized participant-generated path results in a scale factor < 1 . Rotation is the angular offset between the participant-generated and reference paths; less rotation indicates a better match between the produced and reference paths. Shape error was calculated by evaluating the mean distance between corresponding points on the transformed input path and the reference path and, thus, represents how well the participant was able to recreate the qualitative properties of the form irrespective of input scale, location or rotation errors. Lower values represent less ‘error’ and therefore better shape accuracy.

3D tracing—The three-dimensional Cartesian coordinates of the virtual stylus tip and fish were recorded at 50 Hz. These data were filtered using a dual-pass, second order Butterworth filter with a 5 Hz cut-off frequency. Using these data with the known coordinates of the target trajectory (the path), we computed both *temporal* and *spatial* measures of performance. Trial duration was computed as a temporal measure. Trial duration was the time it took for a trial to be completed (the time in seconds from when participants arrived at the starting location to when they arrived at the finish marker). We selected duration because it provides a single unambiguous global measure of performance that related directly to the explicitly stated goal of the task and because it is often used as a performance measure in a wide range of motor tasks. We also examined two *spatial* kinematic performance measures both of which reflected positional error: frequency off path and normed path length. Especially with low spring stiffness, participants tended to come off the path and this cost time (the time required to re-position the stylus). Frequency off path was simply the number of times per trial that this happened (from when participants arrived at the starting location to when they arrived at the finish marker). Normed path length was the total distance travelled (in cm) in a trial by the participant controlled stylus (from when participants arrived at the starting location to when they arrived at the finish marker) divided by the actual wire path length.

We averaged the dependent measures separately for each participant, over the trials performed in a given condition (level of spring stiffness, path) and session (baseline versus post-training). Statistical analyses of the group differences and changes in the dependent measures were performed with mixed design analysis of variance. For these analyses, age (7–8 years old, 10–12 years old) or school (A or B) were between-subjects factors and support level (that is, level of spring stiffness which varied from 0.13N to 2.02N) and session (baseline vs. post-training) were within-subjects factors.

Results

DCD-Q and Beery VMI

First we examined scores for the DCD-Q and the Beery VMI. The median scores for the 10–12 year olds were: 56 (DCD-Q); 64 (VMI); 73 (VP); 50 (MC). The median scores for the previously tested 7–8 year olds were: 61 (DCD-Q); 25 (VMI); 63 (VP); 23 (MC). Using a one factor ANOVA, we tested each of these scores separately for differences between the age groups. The VMI [$F(1, 43) = 38.0$, $p < 0.001$; 7–8 year old mean (std. dev.) = 29.9 (17.2); 10–12 year old mean (std. dev.) = 60.7 (16.2)] and MC [$F(1, 43) = 16.4$, $p < 0.001$; 7–8 year old mean (std. dev.) = 23.7 (19.3); 10–12 year old mean (std. dev.) = 49.7 (23.6)] scores were different, but the DCD-Q and VP scores were not ($p > 0.1$). The 10–12 year old children were at two different private schools, 10 children at one school and 12 at the other. We also tested scores for a difference between the schools and we found differences between the schools in respect to two of the Beery scores. No difference was found for the DCD-Q [mean (std. dev.) = 53.8 (8.0) versus 61.6 (10.2)] or MC scores [mean (std. dev.) = 25.3 (3.4) versus 27.4 (1.58)], but VP [$F(1, 20) = 9.3$, $p < 0.01$; mean (std. dev.) = 77.1 (10.5) versus 59.2 (15.8)] and VMI [$F(1, 20) = 5.0$, $p < 0.05$; mean (std. dev.) = 61.4 (14.1) versus 40.2 (26.1)] scores were significantly different.

3D tracing

We compared performance with respect to duration for traversing the paths in the 3D tracing task at pre-training and post-training. Mean durations are shown in Figure 3 for pre- and post-training assessments at each of the six levels of support and for each age group. To test for learning and age differences as well as an effect of the level of support we performed a mixed design ANOVA on duration with age (7–8 and 10–12) as a between-subjects factor and session (pre-training and post-training) and support level (1–6) as within-subjects factors. The result yielded main effects of age [$F(1, 43) = 6.3$, $p < 0.02$], session [$F(1, 43) = 126.7$, $p < 0.001$], and level [$F(5, 25) = 76.0$, $p < 0.001$] as well as significant age by session [$F(1, 43) = 3.9$, $p = 0.05$] and session by level [$F(5, 215) = 42.8$, $p < 0.001$] interactions. We used Tukey HSD tests to examine the levels of the interactions, first, the age by session interaction. The means at pre-training were 24.3 (7–8 year olds) and 18.3 (10–12 year olds) and at post-training they were 7.6 (7–8 year olds) and 6.6 (10–12 year olds). All comparisons were different ($p < 0.01$), except the comparison of the age groups at post-training ($p > 0.1$). Second, we tested the levels of support by session interaction shown in Figure 3. At pre-training, support levels 4–6 were different from all other levels ($p < 0.01$) both pre- and post-training. None of the support levels was different from any other at post-training ($p > 0.1$). We also performed a repeated measures ANOVA on duration for only the 10–12 year olds with school (A or B) as the between-subjects factor and session (pre-training and post-training) and support level (1–6) as within subjects factors. The reason for including school was to control for the significant difference found for the schools in respect to Beery scores. However, school failed to reach significance ($p < 0.05$) either as a main effect or in any interactions.

In sum, both age groups exhibited improvements in performance in response to training. The younger children performed less well than the older children before training but the two age

groups performed at equivalent improved levels after training. As found in previous studies [13, 14, 18], performance also varied strongly as a function of support level before training, but not after training.

2D drawing

As described in the methods, the children copied nine different forms composed of three variations of three basic types of forms shown in Figure 1. The previous study of 7–8 year olds only entailed figures similar to (but not identical to) the third type used in the current study, that is, waves. Those in the previous study were more difficult, having five rather than three cycles. Because of the differences in the forms copied by the different age groups, we did not directly compare transfer performance in the two age groups. In the previous study of the 7–8 year olds, we had found an improvement in 2D drawing performance as a result of training at the 3D tracing task. We now similarly compared pre- and post-training drawing performance by the 10–12 year olds. Processing of the electronic copies drawn by the children yielded measures of the scale of the copies relative to the target forms to be copied as well as a measure of accuracy in reproducing the shape.

To test shape error scores, we performed a mixed design ANOVA with school (A or B) as a between-subjects factor, and learning (pre-training, post-training) and type (simple, spiral, wave) as within-subjects factors. We included school as a factor to control for significant differences in Beery scores found between the two schools and the possibility that these differences would effect shape production. However, only learning [$F(1, 64)=6.5, p < 0.02$] and type [$F(2, 128)=70.8, p < 0.001$] yielded main effects. Neither school nor any interactions with school was significant ($p > 0.1$). As shown in Figure 4, the overall level of accuracy varied with type. Copies of the simple figures were most accurate, then copies of spirals, and copies of the waves were least accurate. As might be expected from this, the improvement with training was greatest for the waves.

To better understand the errors made in copying, we examined the relation between shape error and scale. A strong relation between scale and accuracy had been found in the previous study. The 7–8 year old children had tended to draw the wave figures too large and to the extent that they did this, they incurred errors in the drawn forms. We found a similar result in the current study of 10–12 year olds, but with a difference that occurred with the difference in forms that were copied, that is, the types of errors differed for the different form types. The tendency was to draw the circular, square and triangular forms too small. This occurred for both the simple or spiral versions of the forms. As before, the tendency for the waves was to draw them too large. The increased and decreased scaling both resulted in the copy yielding proportional errors in the reproduction of the shape (see Figure 5). We performed simple regressions of scale factors on shape error scores separately for the waves and for first two types (simple and spiral) taken together. For simple and spiral figures, the result was significant [$F(1, 130)= 13.3, p < 0.001, r^2 = 0.09$] and the relation was:

$$\text{scale} = 0.04 * \text{shape error} + 0.96 \quad (1)$$

For waves, the result was significant [$F(1, 64) = 25.4, p < 0.001, r^2 = 0.28$] and the relation was:

$$\text{scale} = -0.04 * \text{shape error} + 1.03 \quad (2)$$

The two relations are symmetric and opposite and in both cases, as the scaling went to one (size same as target form), the error in shape approached zero.

Discussion

The goal of the present study was to examine the influence of a new training method for different age groups. Previously, Snapp-Childs et al. [14] tested a method for training good manual compliance control in children with Developmental Coordination Disorder (DCD) by comparing performance before and after training of typically developing children and children with DCD. Before training, the task was exceptionally difficult for the children with DCD to perform without strong support. After training, they could do the task as well as typically developing children either with or without support. Thus, significant differences between the groups were evident in baseline performance but these differences were eliminated in posttest performance. Additionally, Snapp-Childs et al. [18] trained typically developing 7–8 year old children on the 3D tracing task and found that the training transferred to a 2D drawing task. Here, we investigated whether we would find similar results in younger versus older typically developing children by comparing the performance in the new training method of children in two different age groups, namely, 7–8 years of age and 10–12 years of age. In sum, we found a similar pattern of results: 1) older children initially performed better than younger children but, after training, the two groups of children performed equally well independent of the level of support provided; 2) training older children with the 3D tracing task yielded improvements in a 2D drawing task.

Better compliance control should enable children (with or without DCD) to better control their limb when tracing complex 3D shapes and when copying 2D figures. Our training method was designed to improve compliance control in fine motor manual actions, thus we observed the reduction in performance differences between the ages. We liken this to the *enculturated interactions* reviewed by Adolph and Robinson [27]. That is, the experiences that a child has as a result of living in a particular culture or being exposed to a specific set of experiences affects the emergence of developmental milestones and can advance achievements. For example, Lobo and Galloway [28] showed that explicit training of posture and handling of objects yielded earlier emergence of reaching and improved haptic object exploration skills in young infants. Lobo and Galloway concluded that the development of novel behaviors in infancy is dependent on multiple subsystems that can be advanced by manipulating one or more of the critical elements or subsystems. This was in agreement with previous work by Bertenthal and von Hofsten [29], Hopkins and Ronnqvist [30], Thelen [31], and von Hofsten [32]. Here, as with our previous work, we provide empirical evidence that similar interactions are at play throughout childhood.

As previously noted, a goal of the current study was to test, with the older 10–12 year old children, transfer of the training of 3D tracing to 2D drawing. Previously, Snapp-Childs et

al. [18] had tested 7–8 year old children and found that the training transferred to a drawing task. When testing the 10–12 year olds, we now used somewhat different target forms in the drawing task, but we found the same result as before. Training at the 3D tracing task yielded improvements in the 2D drawing task copying 9 different shapes. Also as before, we found that errors in reproducing the shapes were in proportion to the difference in size between the target shape and the copy. However, the different shapes used in the current study yielded different mis-sizing tendencies. Three of the shapes were waves, similar to the shapes used in the previous study. As in the previous study, we found that the waves tended to be copied larger than the target wave. In contrast, the new shapes that we tested in the current study, simple and spiral circles, squares and triangles, tended to be copied smaller than the target versions of the shapes. In both cases, however, mis-sizing yielded errors in reproducing the shapes, and thus, lower shape error. Nonetheless, these findings were encouraging. It was reasonable to expect that older children might not exhibit a transfer effect of the training task to yield improvements in the drawing task. Older children have more experience copying figures, and thus, better control of scale to generate smaller errors. On the other hand, our drawing task was more difficult than typical paper and pencil tasks because it was stylus on glass and thus it required more and better compliance control. Indeed, the older children exhibited improvements like those found for younger children. They all acquired better compliance control.

Finally, the findings of this study paint a more complicated picture with respect to the role of visuo-motor integration and perception and performance on 3D tracing and 2D drawing tasks. Snapp-Childs et al. [18] found that the VP score of the Beery had predicted pre-training performance in both the 3D tracing task and the 2D drawing task performed by 7–8 year old children. Conversely, we found no evidence in this study that the Beery predicted performance in the 3D tracing and 2D drawing tasks. However, the children in this study were older: 10–12 year old versus 7–8 years old. Also, the children in the current study exhibited substantially better Beery scores overall (although we did find a difference in average performance between the two schools at which the children were tested). We suspect that two things are at play here – age and instrument factors. The Beery is a cruder instrument than the tests and measures employed in our studies and thus, is likely to be less sensitive for older children whose overall level of performance is better than that of younger children. This view is consistent with the call for the development of research tools that can record kinematic data but can be portable and easy to use in a relatively uncontrolled environment such as an elementary school classroom [26].

Conclusions

In sum, this approach to training is showing good promise as a means to help children improve in performance of fine motor manual tasks like drawing or potentially, handwriting, and the results indicate that the methods might be well applied within schools.

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Figure 1.
Illustrations of the nine target forms copied by participants.

Figure 2.

A) The PHANTOM Omni with the display illustrating the path used in Pre-training and Post-training trials. B), C), D) Illustrations of the paths used in training in the 3D tracing task.

Figure 3. Mean durations for each support level, session, and age group. Pre-training: circles. Post-training: squares. 7–8 year olds: open symbols. 10–12 year olds: filled symbols. Error bars are standard errors.

Figure 4.

Mean shape error for drawings of each of the three types of target figures both before and after training at the 3D tracing task. Pre-training: filled circles. Post-training: open squares. Error bars are standard errors.

Figure 5. Scale factor plotted as a function of shape error separately for simple and spiral figures (open squares) and waves (filled triangles), each fitted by a line using simple regression. See text for details.