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Balance Training with Visual Feedback in Children with Hemiplegic Cerebral Palsy: Effect on Stance and Gait

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The aim of the present study was to examine the effects of balance training with visual feedback on stance and gait in school-age children with hemiplegic cerebral palsy. Ten participants between 5 and 11 years of age were assigned to either the training or the control group according to an aged-stratified randomization. The training corresponded to three sessions per week during six weeks. Stance and gait parameters, based on force plate data, were assessed three times in both groups: (a) at the beginning of the study (before training); (b) after six weeks; (c) after ten weeks. Spatial and temporal parameters were calculated. The results for stance showed that the training improved the performances on the tasks that were trained. More interesting, the results for gait showed that the walking pattern became more symmetrical after the training.

Key Words: posture, walking, symmetry, equilibrium, development

The majority of children with hemiplegia are able to walk without restrictions but more advanced gross motor skills are often jeopardized (Gorter et al., 2004). Although children and adults with hemiplegia are able to walk without external support they have abnormal gait patterns (Berger, Quintern, & Dietz, 1982; Buckon et al., 2001; Winters, Gage, & Hicks, 1987) including asymmetry between the affected and unaffected leg (Fonseca et al., 2004; Olney, Griffin, & McBride, 1994). Hemiplegia also affects performance on balance tasks during standing in adults (Bonan et al., 2004; Garland, Stevenson, & Ivanova, 1997; Stevenson & Garland, 1996) and in children (Nashner, Shumway-Cook, & Marin, 1983).

Balance training is an important component of rehabilitation programs for patients with hemiplegia and other neurological disorders. Among the different types of balance training, two have been studied in children with cerebral palsy. Balance

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training based on repetitive stance perturbation was recently applied in school-age children with cerebral palsy and showed that a massed practice using a moving platform improved their recovery of stability following an external perturbation (Shumway-Cook et al., 2003). Another type of balance training includes visual feedback of postural sway during unperturbed stance and is aimed to help patients to be aware of their postural sway to improve its control. The general aims for using balance training with visual feedback in patients with hemiplegia can be summarized as follow: to keep the body close to the vertical, to enlarge the boundaries of the area in which the body can oscillate safely, and to reduce left-right difference in weight bearing. According to Duarte and Zatsiorsky (2002), the first two aims offer advantages for the maintenance of stance: first, small body oscillations close to the vertical reduce muscle activity, which requires less energy, and second, larger distances between the gravity line and the limits of stability are safer and make recovery from perturbations more successful. Reducing left-right difference in weight-bearing is thought to increase the functional base of support during stance which improves stance stability. Another benefit of an enhanced weight bearing on the affected leg in children with hemiplegia concerns bone growth since a left-right discrepancy has been suggested to affect bone mineralization which reduces bone size and density of the affected limb (Lin & Henderson, 1996).

In hemiparetic adults, balance training including visual feedback of the weight shifts of the whole body has been successful when standing (Brouwer et al., 1998; Chen et al., 2002; Liston & Brouwer, 1996; Sackley & Lincoln, 1997; Shumway-Cook, Anson, & Haller, 1988) and when sitting (Mudie et al., 2002). A common result was improvement in postural symmetry that sometimes generalized to improved performance in skills such as walking or climbing stairs (Sackley & Lincoln, 1997). One study showed positive effects of a frequent weight-shift practice with visual feedback in four children with diplegia (Hartveld & Hegarty, 1996). The training seemed to improve the time they could stand without aid on both feet or on one foot for some of them.

The aim of the present study was to examine the effects of balance training when standing with visual feedback on stance and gait in school-age children with hemiplegia. We hypothesized that this type of training will enable the patients to (a) reduce body oscillations and (b) to actively explore, and hence increase, the limits of the base of support. We also hypothesized that the training would improve the ability to equally distribute body weight across the two feet, which will increase the step length symmetry during walking by increasing the step length when the non-paretic leg swings forward. This hypothesis concerns the indirect effect of the training on a task that was not specifically trained.

Method

Participants

Ten children with congenital hemiplegia between 5 and 11 years of age were recruited from the medical center of the Vrije Universiteit in Amsterdam. Inclusion criteria were: (a) a level I rating on the Gross Motor Function Classification System for children with cerebral palsy (Palisano et al., 1997) which corresponds to the ability to walk independently; (b) participation in a normal educational program;

(c) no uncorrected vision or hearing impairments; (d) no surgical intervention in the 12-month period prior to the study and no botuline toxin treatment or plaster treatment in the 6-month period prior to the study. Written informed consent was obtained from the parent(s) of each participant and the children gave their verbal informed assent.

The participants were assigned to two groups following an age-stratified randomization to obtain a comparable age range in both groups. The average ages of the training group and the control group were 7 years and 2 months, and 7 years and 7 months, respectively.

Instrumentation

Balance was both tested and trained on the same static force plate (1 m × 1 m), which measured the vertical ground reaction forces. The center of pressure (COP) was calculated online by the acquisition system (sampling frequency 100 Hz). Gait analysis was based on the data from two synchronized force plates (1 m × 1 m) as described above (sampling frequency 200 Hz). The force plates were in the middle of a walking track of 4 m and were used to measure two to four consecutive steps per trial depending on the child's step length.

Training Procedure

The children in the training group received 18 sessions of balance training at the university laboratory corresponding to three sessions per week during six weeks. Each training session lasted approximately 30 min and included static and dynamical tasks.

The force plate was displayed as a square (40 cm × 40 cm) on a vertical screen (2.5 m × 2.5 m), situated at a distance of 1.3 m in front of the child standing at the center of the force plate. The COP was represented by a red dot. The children were required to either keep the dot within a target area located directly in front of them at an eye height that corresponded to the center of the base of support (static task), or to move the dot towards successive positions occupied by the target area (dynamic tasks). Three dynamic tasks were performed: (a) a "circle task," in which the target areas appeared at regular distances along a circle path in either a clockwise or counter-clockwise direction, (b) a "random task," in which the targets appeared at unpredictable (randomly selected) places, and (c) a "lateral weight-shifting task," in which the target area moved continuously to and fro between the center and either a position to the left or right of the center. During the latter task the distance was gradually increased. This distance was also progressively increased from one trial to the next when the participant was able to reach the most distant located target.

Stance and Gait Evaluation

This study included three evaluations of stance and walking: one prior to the start of the training (pretest), the second within one week after the last training session (post-test), which was six to seven weeks after the first evaluation, and the third within 10 weeks after the first evaluation (follow-up test). Control group participants did not receive training but had the same stance and gait evaluation as the training group. Throughout the experiment the children wore their own shoes including ankle-foot ortheses or insoles that corrected leg-length discrepancies.

Stance evaluation was performed in quiet and dynamic standing. Measurement of quiet standing corresponded to the static task of the training and the measurement of dynamic standing was similar to the lateral weight-shifting training task in which forward and backward weight shifts were added.

Before the first evaluation, one of the trainers (J.K. or R.M.R.) demonstrated how to stand on the force plate and how to move the dot on the screen from movements about the ankles leaning forward, backward, and on the left and right side without moving their feet. Then the participant was asked to try out and to find a comfortable foot position with the arms along the body. The trainers verified that the child understood the functioning of the feedback system and that he adopted a suitable feet positioning. Distance between the feet had to correspond to the width of the pelvis and their orientation had to be as parallel as possible to the anterior-posterior axis of the force plate. The position of the feet was drawn on a sheet of paper fixed to the force plate. This positioning was maintained for all the evaluations of stance and during the training.

Gait was evaluated when walking along the 4-m walkway that included the two force plates. They walked independently at their preferred speed without a walking aid. A total of 10 gait trials were recorded at each test.

Data Analysis

The following dependent variables were measured at the three test moments:

- Time on target during quiet standing: percentage of time the red dot was kept within the target area.
- Maximum amplitudes of COP displacement during quiet standing in the forward, backward, toward the paretic and the non-paretic side.
- Maximum amplitudes of COP displacement during dynamic standing when leaning forward, backward, toward the paretic and toward the non-paretic side.
- Step length was calculated from the displacement of the COP along the progression axis during walking and defined as the distance between two successive foot contacts.
- Step length asymmetry was defined as the relative difference between step length when the paretic leg was swinging forward and when the non-paretic leg was swinging forward as a percentage of the average step length from both sides.

Amplitudes of COP and step length were calculated with respect to the child's height to compensate for differences in body dimensions between individuals.

The average spatial and temporal parameters during standing and the average step lengths of all walking trials were calculated for each participant and each evaluation. Changes over time and differences in stance between groups were investigated using repeated measures analysis of variance (ANOVA) with moment of testing as the within-subject factor. The Greenhouse Geisser correction was applied where there was significant sphericity in the data. Simple one-way ANOVA was used to test the effect of the moment of testing within each group. An alpha value of .05 was used for all statistical analyses.

Results

Evaluation of Quiet Stance

Figure 1 shows the maximum amplitude of COP displacement during standing still in the four directions for both groups. The main effect of the moment of testing on the maximum amplitude of sway was significant for the forward and backward directions [$F(2,18) = 6.24$, $p = .01$ and $F(2,18) = 7.07$, $p = .006$, respectively] but failed to be significant toward the paretic and non-paretic leg [$F(2,18) = 1.28$ and $F(2,18) = 2.28$, respectively]. The moment of time × group interaction was significant for the backward and paretic directions [$F(2,18) = 8.79$, $p = .003$ and $F(2,18) = 4.51$, $p = .028$, respectively]. One-way ANOVAs within each group showed that the amplitudes significantly decreased with time for the forward and backward directions [$F(2,12) = 4.30$, $p = .039$, and $F(2,12) = 5.03$, $p = .026$, respectively] in the training group but not in the control group.

Figure 2 shows that the time spent on the target during quiet standing increased in both groups. Changes over time were significant [$F(2,18) = 4.82$, $p = .023$] but no significant interaction effect between time and groups was observed.

Evaluation of Dynamic Stance

Figure 3 shows the maximum voluntary displacement of COP in all directions in both groups separately. Repeated measure ANOVAs showed that the main effect of moment of testing was significant in all four directions [$F(2,18) = 8.50$, $p = .003$ for forward; $F(2,18) = 14.53$, $p < .001$ for backward; $F(2,18) = 4.92$, $p = .022$ for the paretic side; $F(2,18) = 13.96$, $p < .001$ for the non-paretic side]. The one-way ANOVAs within each group showed that the amplitudes significantly increased with time in the training group for the forward and backward directions and towards the non-paretic side [($F(2,12) = 10.30$, $p = .002$; $F(2,12) = 4.92$, $p = .027$; $F(2,12) = 5.46$, $p = .021$, respectively]. No significant effect of moment of testing was observed in the control group.

Gait Evaluation

Figure 4 shows, for each group, the average relative step length (and standard deviation) when the paretic and the non-paretic leg were swinging forward. The repeated measure ANOVAs showed that the step length was significantly increasing with time when the non-paretic leg was swinging forward [$F(2,18) = 5.32$, $p = .017$] and the effect of time was not significant when the paretic leg was swinging forward. The repeated measure ANOVA for step length asymmetry showed that the amount of asymmetry significantly decreased with time [$F(2,18) = 4.95$, $p = .021$] and that the interaction (group × moment of testing) was not significant. Since the initial asymmetry at pretest was significantly larger in the training group than in the control group (Student $t = 2.5$, $df = 8$, $p = .04$) we tested the difference between step length on the paretic and non-paretic legs for each testing moment and each group separately. Step length, when the paretic leg was swinging forward, was significantly longer than when the non-paretic leg was swinging in the training group at the pretest (Student $t = 4.07$, $df = 4$, $p = .015$) but not at the post-test and follow-up test. No significant differences were observed in the control group.

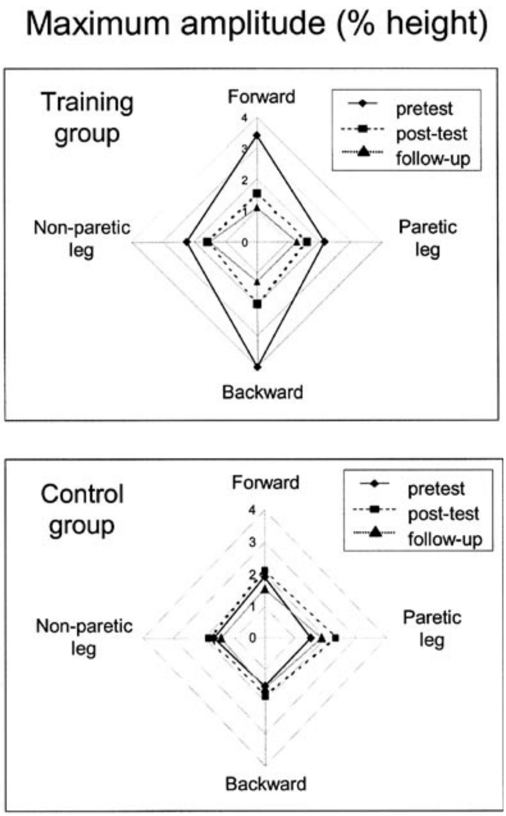

Figure 1—Maximal amplitude of center of pressure during quiet standing (the units on the axes represent percentages of children's height). The sway amplitude toward the affected leg is presented on the right, which does not always correspond to the right side of the participant.

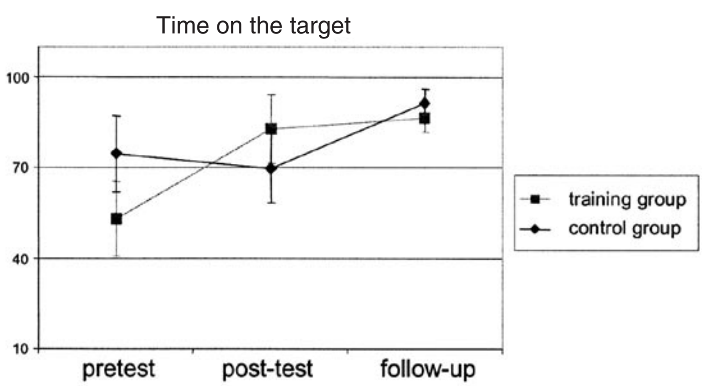

Figure 2—Percentage of time the center of pressure was maintained on the target.

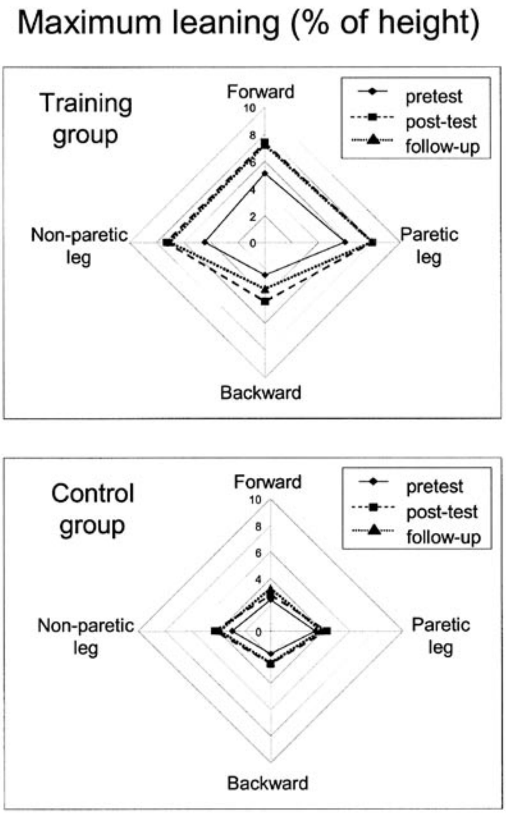

Figure 3—Maximal amplitudes of center of pressure during dynamical standing (the units on the axes represent percentages of children's height) for the training group (upper panel) and the control group (lower panel).

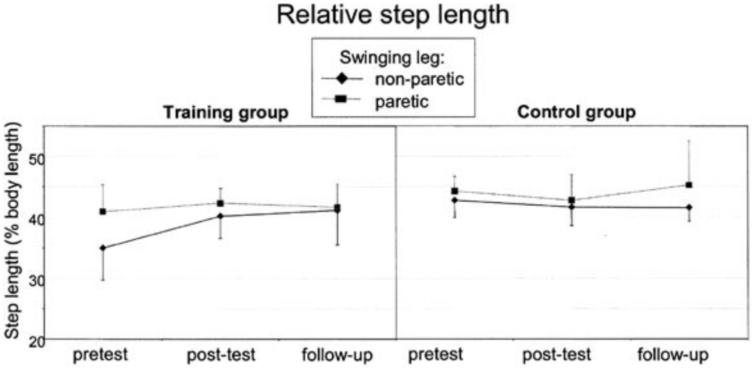

Figure 4—Average relative step length when the paretic leg was swinging forward (solid rectangle) and when the non-paretic leg was swinging forward (solid diamond) in the training group (left) and the control group (right).

Discussion

The results of the present study suggest that balance training with visual feedback might be useful to decrease the amplitude of postural sway during quiet standing and increase the amplitude of the voluntary weight shifts during standing. In addition, the training resulted in a decrease of the asymmetry in step length during walking.

The training group showed increases of the voluntary weight shifts in the forward and backward directions and toward the non-paretic leg whereas no increase was observed in the control group. In the training group, postural sway during quiet stance appeared to be more stable after the training as indexed by smaller amplitude of the maximum sway in the forward and backward directions. The parallel increase of time on the target confirms that the children became better in quiet standing with visual feedback.

In other words, after the training the children improved the performances on the tasks that were trained by reducing the amplitude of postural sway and enlarging the area of possible weight-shift without making a step or fall.

With regard to gait, balance training resulted in an increase in step length when the paretic leg was supporting (thus non-paretic leg was swinging forward). Step length asymmetry was previously observed in hemiparetic children and interpreted as the result of weakened relevant muscles (e.g., ankle plantar flexors and hip flexors and extensors) of the affected leg (Fonseca et al., 2004). In hemiplegic adults, the spasticity of the affected ankle plantar flexors was the primary determinant of step length asymmetry during gait (Hsu, Tang, & Jan, 2003). In the present study, the weight shifts included in the training might have helped to exercise these relevant ankle muscles. Unfortunately, spasticity of the ankle plantar flexors was not measured in this study, but the initial difference in step length asymmetry between the training and the control group might be related to differences in spasticity levels in the two groups. Further research on the effect of balance training on gait should control for this factor.

There is evidence to suggest that balance and locomotor abilities are positively correlated in adults with hemiplegia (Richards et al., 1995) and in children with spastic diplegia (Liao et al., 1997). In the latter study, children with spastic diplegic CP had a decreased rhythmic shifting ability compared to non-CP children and this ability was correlated with walking function. The present study supports the suggestion of Liao et al. (1997) to use rhythmic weight-shift training to improve the walking performance of children with CP. The ability to initiate and control voluntary weight shifts toward either leg is an important prerequisite for walking and it is therefore not surprising that weight-shifting training has an impact on asymmetrical gait pattern (Haart et al., 2005). Although the association between quiet standing and walking seems less straightforward, it has been shown that postural control during quiet standing was related to the weight-shifting ability suggesting that both tasks rely, at least in part, on the same physiological mechanisms (Haart et al., 2005).

In conclusion, the results of the present pilot study suggest that balance training with visual feedback, including weight-shifting tasks when standing, might be successfully used in children with hemiplegia. The training improved the tasks that were trained during quiet and dynamical standing and improved gait symmetry indexed by a significant reduction of step length asymmetry between the paretic and non-paretic leg.

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