Feasibility of Using an Arm Weight–Supported Training System to Improve Hand Function Skills in Children With Hemiplegia

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MeSH TERMS
- exercise therapy
- hemiplegia
- motor skills
- psychomotor performance
- upper extremity
- user–computer interface

OBJECTIVE. This investigation was a pilot feasibility trial evaluating the use of an arm-weight–supported training device to improve upper-extremity function in children with hemiplegia.

METHOD. A single-group within-subject design was used. Participants were 6 children ages 7–17 yr with upper-extremity weakness secondary to hemiplegia. The intervention consisted of 15–18 treatment sessions using an arm-weight–supported training device with the affected upper extremity. Fine motor function was assessed using the Jebsen–Taylor Hand Function Test, the Box and Block Test, and the Assisting Hand Assessment. We examined participants' interactions with the device and assessment scores pre- and postintervention.

RESULTS. Five of the 6 children exhibited some changes after the therapy. The system required significant modifications to ensure appropriate positioning.

CONCLUSION. The arm-weight–supported system may be viable for therapeutic use. Future studies should use randomized controlled designs and compare effectiveness of weight-supported training with that of other rehabilitation strategies.

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Children with hemiplegia present with weakness and motor skill deficits on one side of the body. Hemiplegia affects the arm and leg and often limits a child's ability to perform activities of daily living. Hemiplegia can be caused by stroke, structural malformations, congenital or perinatal injury, and arteriovenous malformations (Lloyd-Jones et al., 2008). Stroke affects 1 in 4,000 live births per yr in the United States. The risk of a cerebral event in children between birth and age 18 yr is 11 per 100,000 children annually, with the highest risk occurring earlier in life (Lloyd-Jones et al., 2008).

Therapeutic interventions for adults and children with unilateral arm and hand weakness include physical therapy, occupational therapy, prescribed orthoses, and home-based exercise. Treatment approaches in physical and occupational therapy are evolving in response to new research in motor learning and skill acquisition. Specifically, an evidence base is emerging for the effectiveness of constraint-induced movement therapy (CIMT), hand–arm bimanual intensive training (HABIT), neurodevelopmental therapy, and the use of intramuscular botulinum toxin type A combined with upper-limb training (Sakzewski, Ziviani, & Boyd, 2009). A recent review suggested large effect sizes for combination treatment with task practice and botulinum toxin type A and small to medium effect sizes for other treatment approaches (Sakzewski, Gordon, & Eliasson, 2014).

Task practice and repetition are common features of many treatments for hemiplegia (Kaplan & Bedell, 1999; Schmidt & Lee, 2005; Whyte, 2009).

Robotic-assisted training, and arm training devices in particular, now automate and enhance practice and repetition (Reinkensmeyer, 2012; Shin, Ryu, & Jang, 2014). Most of these devices include a virtual reality interface in which participants play games or complete virtual activities while practicing repetitive upper-extremity movements (Maciejasz, Eschweiler, Gerlach-Hahn, Jansen-Troy, & Leonhardt, 2014). Some of these robotic devices provide active assistance (multimodal neuroprosthesis for daily upper-limb support) or incorporate haptic or tactile feedback (CyberGrasp, CyberGlove Systems, San Jose, CA), whereas others facilitate movement by assisting in managing the weight of the affected arm while engaging in tasks, such as the therapy Wilmington robotic exoskeleton (T–WREX), developed at the University of California at Irvine and later improved on and manufactured as Armeo®Spring (Hocoma AG, Volketswil, Switzerland; Maciejasz et al., 2014).

Several nonreplicated studies with robots and gravity-assisting devices have demonstrated improvements in upper-extremity function in adults (i.e., T–WREX; Hocoma AG, 2010). The T–WREX is an adaptation of the WREX (*W*ilmington *R*obotic *EX*oskeleton upper-extremity orthosis), which was evaluated in a report examining children diagnosed with arthrogryposis multiplex congenita and spinal muscular atrophy (Haumont et al., 2011). Randomized controlled trials have documented improvements in function compared with conventional therapy in adults (Housman, Le, Rahman, Sanchez, & Reinkensmeyer, 2007; Sanchez et al., 2006). No published research to date, however, has investigated the T–WREX in children with upper motor neuronal lesions.

Two randomized controlled trials have tested the effectiveness of the ArmeoSpring in the treatment of adults with acquired hemiplegia. In the first, Prange et al. (2014) found that the ArmeoSpring was well tolerated, and its use facilitated greater interest in treatment for 70 adults receiving stroke rehabilitation. Both the treatment group and the control group (which received traditional therapy) made significant gains in motor functioning and upper-extremity capacity as measured by the Fugl-Meyer Assessment (FMA; Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975), maximal reach distance, the Stroke Upper Limb Capacity Scale (Roorda, Houwink, Smits, Molenaar, & Geurts, 2011), and a visual analog scale (for arm pain; Monk, 1989). However, no additional treatment benefits of this arm-weight–supported training method were observed. In the second study, Bartolo et al. (2014) found that the ArmeoSpring improved function in 28 adults with acute stroke. Upper-extremity gains were measured with the FMA, the FIM™ (Uniform Data System for Medical Rehabilitation, 1997), and kinematic analysis of upper-extremity movement. Both the treatment group and the control group made significant functional gains, but only the treatment group exhibited improvements with range of motion in abduction and adduction.

We are unaware of any published reports describing the effectiveness of arm-weight–supported training devices for children with unilateral arm and hand weakness. The objective of this study was to describe efforts to test the feasibility of using a commercially available arm-weight–supported training device (i.e., ArmeoSpring Pediatric, Hocoma AG, Volketswil, Switzerland) to improve function in children with unilateral arm and hand weakness secondary to brain injury or structural malformation. We also examined the effects of treatment using this device on fine motor functioning, gross manual dexterity, and assisting hand function.

Method

Research Design

This study was a feasibility trial to examine the usability and effectiveness of an arm-weight–supported device (ArmeoSpring Pediatric). Data were collected between June and December 2014.

Participants

Study information was provided to all families of children with hemiplegia treated in the facility's inpatient or outpatient treatment programs. The study was then reviewed with any family expressing interest in participating. Families of 8 children consented to participate; however, 1 child failed to meet the criteria for hemiplegia at initial assessment and another child dropped out before completing 15 treatment sessions. Therefore, participants included 3 boys and 3 girls (Participants 1–6; Table 1) between ages 7 and 17 yr (mean [*M*] age = 10.83 yr, standard deviation [*SD*] = 3.37) who demonstrated impaired tone, range of motion, or strength, or a combination of the three, during evaluation by an occupational therapist and a physiatrist. They presented with a broad range of conditions underlying their upper-extremity weaknesses, varying left or right hemiplegia, and different ambulation abilities (see Table 1). All met basic measurement parameters to use the device (upper arm length between 155 and 235 mm; lower arm length between 230 and 370 mm), and all completed at least fifteen 30- to 40-min sessions over 6–8 wk (Participants 1, 3, and 4, 15 sessions; Participants 2, 5, and 6, 18 sessions). All procedures

Table 1. Participant Demographic and Clinical Characteristics

Participant	Age, yr	Gender	Condition	Ambulation	Affected Side
1	10	M	Cerebral palsy–related hemiplegia	Ambulatory with support; uses a wheelchair for long distances	R
2	17	M	Stroke-related hemiplegia	Ambulatory with close supervision	L
3	11	F	Cerebral palsy–related hemiplegia	Independently ambulatory	R
4	7	M	Polymicrogyria	Independently ambulatory	L
5	9	F	Sturge–Weber syndrome	Independently ambulatory for short distances; uses a wheelchair for long distances	L
6	11	F	Obstructive hydrocephalous/hemiplegia	Uses a wheelchair	L

Note. F = female; L = left; M = male; R = right.

were approved by the facility's institutional review board, and parents of the participants provided written consent for their child to participate.

Measures

Participants were evaluated with the Jebsen–Taylor Hand Function Test (JTT; Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969), the Box and Block Test (BBT; Mathiowetz, Volland, Kashman, & Weber, 1985), and the Assisting Hand Assessment (AHA; Krumlinde-Sundholm, Holmefur, Kottorp, & Eliasson, 2007). The JTT includes seven subtests that measure hand function in adults and children with unilateral impairments and measures speed of task completion rather than the quality of movement patterns (Sears & Chung, 2010): (1) Writing a 24-Letter Sentence, (2) Card Turning, (3) Placing Small Objects (e.g., pennies, paper clips, bottle caps) in a Container, (4) Stacking Checkers, (5) Simulated Feeding, (6) Moving Light Objects (e.g., empty cans), and (7) Moving Heavy Objects (e.g., 1-lb cans). The evaluator presents the participant with the test input and records time to completion.

Strong test–retest reliability for the JTT (intraclass correlation coefficients between .72 and .74) was documented in a recent trial of typically developing children (Beagley, Reedman, Sakzewski, & Boyd, 2015), and the JTT has been used in research assessing upper-extremity therapy in children and adolescents (Klingels et al., 2012). For this study, six subtests were administered; the Writing subtest was not administered. The BBT is another well-normed and validated measure of manual dexterity (Mathiowetz et al., 1985; Platz et al., 2005); it assesses the number of blocks a person can transfer from one box to another in 60 s. Both the JTT and the BBT assess each hand separately.

The AHA measures how effectively children with unilateral upper-limb impairment use their affected hand and arm (i.e., the assisting hand) in play requiring bilateral performance. Sessions are semistructured and videotaped and then scored. The test includes 22 items describing different arm and hand functions. It is scored on a 4-point scale rating performance, and the sum of scores may vary from 22 to 88 points. This test provides scores on an ordinal scale, unlike most other assessments, which are on an interval scale. Although an increase in raw score indicates that a greater number of items were scored higher, it does not mean that more difficult items were passed. This assessment has acceptable reliability, and it determined distinct ability levels in a large sample of children with hemiplegia (Krumlinde-Sundholm et al., 2007).

Procedures

Study procedures were completed at a suburban pediatric subacute rehabilitation facility serving a large, diverse metropolitan area. The intensive therapy was provided during a summer day camp program sponsored by the rehabilitation center. Before beginning the intervention, each child was screened and assessed by the primary researcher (Krishnaswamy). Assessments of hand function were made before and immediately after the intervention and were completed in one or two sessions.

Intervention

The ArmeoSpring Pediatric device was developed for children to facilitate repeated practice by providing spring assist to reduce the effects of gravity on the affected arm. This device requires individualized device and software settings, including options for upper-arm length and forearm length as well as nine levels of upper-arm weight compensation and five levels of forearm weight compensation. Software individualization was used to measure each participant's grip threshold (33% of the client's maximum grip force), active grip pronation, grip supination, wrist flexion, and wrist extension. Games were then modified to fit each participant's parameters, and each participant was then presented with challenges in his or her active range of control.

Each participant engaged the ArmeoSpring Pediatric device in a virtual area of control. This space is three-dimensional in virtual reality and allows the participant forward reach, lateral reach, and upward and downward

arm motion. Once this three-dimensional space was individualized, the participant selected from an array of games (developed by Hocoma AG) that required single movements (e.g., wrist flexion, wrist extension, elbow flexion, elbow extension) or combinations of movements. The system included a pressure-sensitive, cylinder-shaped joystick that simulated a mass grasp for the child. Feedback provided by this device was primarily visual, with some proprioceptive feedback obtained from the pressure handgrip.

Each participant was positioned to ensure appropriate device alignment and to account for software individualization. Modifications were necessary to facilitate alignment with the arm orthosis, including the use of extra hook-and-loop straps and mechanical blocks so the orthosis did not collide with the participant's thigh during sessions. The occupational therapist provided verbal redirection to remind the participant to use only one arm during the intervention. Difficulty and duration of play were increased as the sessions progressed.

Each participant received 15–18 treatment sessions distributed 3 times weekly over 6–8 wk. Sessions lasted 30–40 min. Participants also received adjunctive physical therapy and speech therapy sessions as mandated by their treatment plan.

Data Analysis

We calculated the percentage change between pre- and postintervention scores for each participant on the JTT (mean scores of the six subtests administered), the BBT, and the AHA. Table 2 provides these percentage changes and scores for each test. Descriptive data, including means, ranges, and standard deviations, were also examined.

Results

Device Usability Analysis

The device (ArmeoSpring Pediatric) had several features that made it easy to use. It was small, could be moved with ease, and switched to treat the right or left extremity. Electrical and software setup was relatively quick and did not interfere with the therapeutic games. The device was used in this subacute treatment setting primarily by occupational therapists. Training was provided by Hocoma AG, and the occupational therapists supplemented this training with practice sessions to improve ease of use and device-related problem solving. Moreover, the activities captured the participants' interest, and all participants remained attentive and verbalized that they enjoyed the games. However, we also experienced unexpected challenges in deploying the device. We followed arm measurement criteria as suggested by the device manual (Hocoma AG, 2010), yet significant alterations were required during treatment sessions. For example, hook-and-loop straps were needed to ensure proper alignment of participants' forearm with the device, and self-adhering wraps were used to align their wrist and hand with the device gripper. These modifications were particularly necessary for younger children with shorter stature, for whom the system's design proved to be a suboptimal match.

As expected when adapting procedures from adult to pediatric populations, significant therapist encouragement was required to engage child participants and to facilitate task completion, particularly during the initial treatment sessions. Each participant required hand-over-hand assistance to teach task demands, and most participants experienced difficulties comprehending tasks designed within a three-dimensional space. However, once each participant learned the movement required to complete a presented task, assistance from the occupational therapist in using the device was no longer required.

Patterns of Improvement

Five of the 6 participants showed improvement in hand functioning as measured by the JTT and in bimanual function as measured by the AHA. Fine motor dexterity assessed by the BBT improved in 4 participants (see Table 2).

Table 2. Pre- and Posttest Scores and Percentage Changes

	Mean JTT Score, s			AHA Score			BBT Score		
Participant	Pretest	Posttest	% Change	Pretest	Posttest	% Change	Pretest	Posttest	% Change
1	26.33	22.80	13.40	73.00	85.00	16.44	27.00	25.00	−7.41
2	164.16	145.48	11.38	—	—	—	0.00	2.00	200.00
3	117.41	111.58	4.96	62.00	66.00	6.45	13.00	14.00	7.69
4	166.17	133.59	19.60	47.00	47.00	0.00	1.00	4.00	300.00
5	180.00	180.00	0.00	12.00	18.00	50.00	0.00	0.00	0.00
6	85.67	77.98	8.98	45.00	48.00	6.67	4.00	9.00	125.00
Total mean	140.78	122.59	10.18	47.00	48.00	6.67	2.50	6.50	66.70

Note. — = not applicable (AHA not standardized for Participant 2's age); AHA = Assisting Hand Assessment; BBT = Box and Block Test; JTT = Jebsen–Taylor Hand Function Test.

JTT subtest scores indicated that the largest gains were found for the Moving Heavy Objects subtest (*M* change = 40.55 s, *SD* = 39.91; Table 3). However, the participants did not make any gains on the Placing Small Objects in a Container subtest, in which 5 of the 6 participants were unable to complete the task either pre- or postintervention. Surprisingly, 4 participants showed gains on the Card Turning subtest (*M* change = 17.73 s, *SD* = 30.04).

Discussion

Our study represents the first reported data using arm-weight–supported therapy in children with hemiplegia. The purpose of this study was to investigate the feasibility of using an arm-weight–supported training system to improve hand function in children with unilateral arm and hand weakness.

Overall, we found the system easy to use, and all participants appeared to enjoy the activities. The hardware design, however, required revisions so that it could be used with our child and adolescent participants. Although we followed measurement directions provided by the manufacturer of the ArmeoSpring Pediatric, participants required increased support with wraps to facilitate better alignment. We also noted that the design of the ArmeoSpring Pediatric may not have adequately incorporated anthropometric information of developing children. In addition, the system used an exoskeleton to support the arm weight with a spring assist and involved the use of a hand pressure grip. This pressure grip provided the participants with one type of grasp (i.e., mass). Although the visual stimuli on the screen varied, the pressure grip stayed the same and therefore limited grasping options. Although the benefits of massed task practice on the motor learning of children with cerebral palsy is well documented (Gordon et al., 2008; Taub, Uswatte, & Pidikiti, 1999), motor learning is task and object specific (Guadagnoli & Lee, 2004). Therefore, functional gains were likely limited to objects similar to the gripper used in the system.

Research has suggested that the active ingredients of therapy for hemiplegia should include participant engagement, task practice, and functional activities (Dobkin, 2004). However, although the ArmeoSpring Pediatric was developed in line with these components, the percentage gains made by our individual participants were modest.

Therapeutic gains made by some of the participants could have been facilitated by the opportunity to engage in repetitive movements within a virtual reality platform. The elimination of gravity eased task completion and facilitated repetition with less fatigue. Participant gains could also be related to the therapy frequency (3×/wk). Future research should compare the effects of arm-weight–supported device training with those of conventional treatment using similar rates of intensity.

Observed changes in functioning may have been attenuated by the system's initial design, patterned to support the shoulder and arm movements of adults. Improvements may also have been limited by the intensity of training. Our participants received 18 (30- to 40-min) sessions over 6–8 wk, an intensity comparable to similar studies in adults with hemiplegia (Bartolo et al., 2014; Prange et al., 2014). However, CIMT and HABIT demonstrate large effects in children with hemiplegia, but treatment is usually dosed at higher intensities (i.e., 60–120 hr of therapy distributed over 3–8 wk; Gordon et al., 2008; Huang, Fetters, Hale, & McBride, 2009). Huang et al. (2009) reviewed CIMT trials and demonstrated that therapy effects were stronger with increased hours of practice. Future studies should compare the effects of ArmeoSpring Pediatric therapy with matched hours of CIMT and HABIT.

Limitations

This study was an open pilot study with 6 participants treated and assessed by a single provider. Although the results indicate a change in participant hand function

Table 3. Subtest Change Scores on the Jebsen–Taylor Hand Function Test

Participant	Moving Heavy Objects	Moving Light Objects	Stacking Checkers	Simulated Feeding	Placing Small Objects in a Container	Card Turning
1	−6.50	−10.32	6.70	−5.36	4.88	−1.96
2	24.74	0.00	0.00	13.97	0.00	73.35
3	79.10	−4.06	−41.95	0.00	0.00	1.87
4	84.53	43.69	35.44	0.00	0.00	31.78
5	0.00	0.00	0.00	0.00	0.00	0.00
6	61.44	0.00	−8.40	−8.25	0.00	1.35
Mean change (*SD*)	40.55 (39.91)	4.89 (19.43)	−1.37 (24.58)	0.06 (7.64)	0.81 (1.99)	17.73 (30.04)

Note: *SD* = standard deviation. Change scores were calculated by subtracting posttest scores from pretest scores. Positive numbers mean improvement in speed, and negative numbers indicate a decrease in speed.

skills, the small sample for this trial precluded the use of inferential statistics because of power limitations. Use of a larger sample, a control group, and randomized assignment would enhance study power and generalizability. In addition, our participants were heterogeneous at various stages of treatment within a long-term care rehabilitation program and were in the severely impaired range of functioning overall. Therefore, findings should be generalized to other pediatric populations with caution. However, the observed pattern of changes in this study might indicate that children with fewer impairments may make greater gains than our participants.

Implications for Occupational Therapy Practice

Occupational therapy practitioners frequently treat children with cerebral palsy or acquired injury to improve arm and hand function. Practitioners typically encourage the use of the affected hand through play activities requiring object manipulation and problem solving. Use of computers, touch pads, and virtual reality as therapeutic modalities has increased because of easier access and the assumption that novel, stimulating technology facilitates client motivation. In addition, most of these new approaches are designed for adults (e.g., the ArmeoSpring was originally developed for adults with stroke hemiplegia and has only recently been adapted for children), and evaluation of their use with children typically lags behind adult research. Therefore, this study has the following implications for occupational therapy practice:

- Our findings suggest that this device was enjoyable and easy to use but required modifications and extensive instruction to facilitate performance in children.
- This system may facilitate arm strength, particularly gross motor strength; therefore, evidence for its effectiveness needs to be further researched.

Conclusion

This study was a pilot to assess an arm-weight–supported training device for children with unilateral arm and hand weakness secondary to a brain injury or structural malformation. The system was easy to use but had design limitations that needed to be remediated. With respect to therapeutic gains, reevaluation of design characteristics and game design may be important. Modest improvements in hand function were observed, but larger, sufficiently powered trials are needed to better assess the therapeutic effectiveness of this device. ▲

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