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Case Report

Short-term and sustained effects of a three-week neuro-developmental treatment intensive: A case series report

Mary Scott Swiggum[a,*], Jane Knowlton[b] and Denise Powers[b]
[a]*Wingate University, Wingate, NC, USA*
[b]*Pediatric Therapy Center, Houston, TX, USA*

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Abstract.
BACKGROUND: Neuro-Developmental Treatment (NDT) currently embraces evidence-based concepts of motor control, motor learning and neuroplasticity. However, most research has been performed on outdated models of NDT.
OBJECTIVE: This case series examines the short- and long-term outcomes of a three-week intensive using contemporary NDT interventions.
METHODS: Six children, 2–10 years old with neurologic disorders and Gross Motor Function Classification System (GMFCS) levels I-III participated in the intervention. The three-week intensive included 60 minutes of physical, occupational and speech therapy 3–5 times weekly.
RESULTS: All children demonstrated Gross Motor Function Measure-66 gains of medium to large effect sizes. These gains were maintained or improved upon 3 months' post conclusion of the intensive intervention.
CONCLUSIONS: This study supports emerging research regarding the effectiveness of intensive intervention and further study of current NDT interventions.

Keywords: Intensive intervention, cerebral palsy, NDT

1. Introduction

Neuro-Developmental Treatment (NDT) was developed by the Bobaths in 1940 to guide therapists in the treatment of individuals with pathology of the central nervous system (Bobath, B 1985, Bobath, K, 1980). The Bobaths viewed NDT as a "living concept" realizing that their interpretations of the pathologies they observed and the interventions they provided were limited by the theoretical constructs and research at the time. Their initial observations were based on Sherrington's theory of a reflex hierarchy (Sherrington, 1947). NDT instructors have modified the theoretical basis and interventions over time (Bierman, Franjoine, Hazzard, Howle & Stamer, 2016). This evolution has varied throughout the world. The current certification courses in NDT in the United States embrace Dynamic Systems Theory (Bernstein,1967), Neuronal Group Selection Theory (Edelman, 1987), The International Classification of Functioning (ICF) Model (WHO, 2020) and current concepts related to motor control, motor learning, and neuroplasticity. See Table 1 for a comparison of the original theoretical constructs and intervention strategies of NDT and the current practice of NDT in the United stated. A hallmark of NDT which has remained constant over the years is

*Address for correspondence: Mary Scott Swiggum PT, PhD, Associate Professor Wingate University, PO Box 159, Wingate, NC 28174, USA. Tel.: +1 (704) 233 8701, Fax: +1 (704) 233 8673; E-mail: m.swiggum@wingate.edu.

Table 1
A Comparison of the Original NDT Practice and Current Practice in the United States

	Original Constructs (Berta and Karel Bobath, 1940)	Commonalities	Current Practice (Bierman, Franjoine, Hazzard, Howle, Stamer, 2016)
Theoretical basis	Sherrington's Theory of a Reflex Hierarchy *There is a hierarchy within the CNS – the higher levels of the CNS guide and control movement*		Dynamic Systems Theory Theory of Neuronal Group Selection *There is a dynamic interplay between the brain, body and the environment*
Intervention strategies	Use of handling to inhibit atypical postures and movements and facilitate typical movements Interventions based on areas of need	Handling is a means to improve motor control Intervention is individualized assessment is continuous Therapy evolves based on the child's response Typical development provides a framework for assessment and intervention	Handling is used judiciously – based on the stage of learning of the child and the stage of motor control Interventions based on areas of strength The child should be allowed to experiment with trial and error movements within a safe environment The child should initiate and control movement as much as possible
Family involvement	The family was instructed in what normal movement patterns were to be encouraged	Carryover of therapeutic activities into the child's daily routine is critical	The family plays a key role in determining goals for the child
Motor learning	Sensory feedback key to obtaining motor control Emphasis on motor performance Child is somewhat passive	Feedback is important Feedback is provided using manual contacts, verbal and nonverbal cues Frequency and intensity of practice is important Repetition is important	Motor learning results from experience and practice. Children must be active during therapy Importance of setting goals in contexts that are meaningful Child is an active participant in therapy
Neuroplasticity and neurorecovery	Recognized that changes could be made – limited by theory and research at the time	Experience is important Repetition is important	Brain can reorganize in response to training, experience and environmental demands

the concept of therapeutic handling. Initially, handling's purpose was to normalize muscle tone and inhibit or facilitate normal movement patterns. Currently, the practice of NDT in the United States views handling as a "dynamic reciprocal interaction between the client and the therapist" to be used as appropriate depending on the client's stage of motor learning and for the purposes of advancing performance of activity and participation goals (Bierman, Franjoine, Hazzard, Howle & Stamer, 2016).

Research on NDT has been inconclusive and mostly based on old, outdated theoretical applications. In a recent systematic review, it was concluded that NDT was an ineffective intervention for children and therefore should be discontinued (Novak, Morgan, Campbell, Morton, Stumbles, Wilson, Goldsmith, 2013). This recommendation was based on older applications of NDT which focused on altering impairments such as muscle tone and contracture and not on the current state of practice which focuses on child specific activity-related goals and participation.

Research on the current model of NDT as embraced by leaders in the United States is scarce. A preliminary study on the effects of intensive NDT (3 times weekly for 6 weeks) on children with cerebral palsy, Gross Motor Function Classification System (GMFCS) levels I-V, utilized intervention and

philosophical approaches consistent with current teachings of NDT in the United States. Analysis of the outcomes of 15 children demonstrated significant improvements in Gross Motor Function Measure (GMFM) scores ($p = 0.009$) and goal total scores ($p = 0.001$) and significant changes in several categories of the Pediatric Evaluation of Disability Inventory (Knox & Evans, 2002).

Another group of researchers examined the effects of differing intensity of NDT intervention (2 versus 5 times weekly for 16 weeks) on GMFM outcomes in 34 children with cerebral palsy, GMFCS levels IV and V (Tsorlakis, Evaggelinou & Tsorbatzoudix, 2004). Both groups improved significantly after the intervention ($p < 0.05$). The high intensity group demonstrated the greatest improvement ($p < 0.05$). The researchers acknowledged that NDT has evolved differently in various countries. They purported to use current models of NDT but did not explicitly define their approach. Park reported that intensive therapy (3–11 times per week) resulted in better functional outcomes than conventional therapy (1-2 times per week) for children with cerebral palsy (Park, 2016). Studies specific to NDT interventions also support intensive intervention over conventional dosing (Tsorlakis, Evaggelinou & Tsorbatzoudix, 2004), Lee, Park,& Lee, 2017).

A pilot study utilizing an updated NDT approach was performed on five children with GMFCS levels IV-V. The children received periods of intense intervention (physical therapy 4 times a week for 4 weeks) followed by 8 weeks without intervention over a 6-month period. Significant changes in GMFM outcomes were reported for 3 children ($p < 0.05$) and all children maintained skills during the periods without intervention (Trahan & Malouin, 2002).

Several researchers have examined the effects of therapy approaches that do not bear the title "NDT" yet when examined appear to be consistent with the current interpretation and application of NDT in the United States. A pilot study utilizing a combined therapy approach was performed on 4 children with GMFCS levels IV or V. The children received therapy daily for 60–90-minute sessions over a period of 8 weeks. The intervention was well described and embraced many of the concepts currently used by NDT certified therapists in the United States but also included intervention approaches such as mobilization with trigger points which is not part of current NDT practice. They reported positive results on the achievement of goals as measured by Goal Attainment Scaling, but no significant changes on GMFM or Pediatric Evaluation of Disability Inventory (PEDI) outcomes (Russel, Scholtz, Greyling, Taljaard & Viljoen, 2017). Conversely, another study reported significant changes in GMFM measures in children with GMFCS levels I-III following a 5-week intervention of task oriented therapy twice weekly (Salem & Godwin, 2009). The task oriented therapy described is consistent with current NDT theory but made no mention regarding techniques, such as physical handling or bracing, to achieve normal alignment and motor control while performing the tasks.

Emerging research on the effects of modern NDT approaches on children with cerebral palsy is positive. However, the therapeutic approach used is not always clear and sometimes "muddied" with other approaches as in Russel et al.'s study (Russel, Scholtz, Greyling, Taljaard & Viljoen, 2017). Research on the effectiveness of current NDT applications, which embrace evidence-based concepts along with emphasis on normal alignment and motor control, as applied in clinics in the United States, is needed. This case series description of 6 children who received intensive NDT therapy in a private outpatient clinic provides a glimpse at the current application of the NDT approach in the United States as well as the outcomes achieved under this updated model.

2. Description of the cases

The children ranged in age from 3–10 years old. The GMFCS levels ranged from 1–3. The GMFCS is a 5-point ordinal scale which classifies children by their motor ability (Palisano, Rosenbaum Walter et al., 1997). Level I represents the highest functional ability. Children at this level are able to participate in the community with minimal deficits. Children classified at a Level 5 are typically fully dependent on others for care and are transported in wheelchairs. The GMFCS has excellent interrater reliability (0.993-0.996) and intrarater reliability (0.972-0.996) (Ko, Woo, Her, 2011). Table 2 provides the ages, GMFCS levels, and functional abilities of each child.

3. Description of the intervention

The intervention consisted of a 3-week intensive program (60 minutes of physical, occupational, and speech therapy intervention, 3–5 times weekly). One child received intervention 3 times a week while

Table 2
Description of the Cases

Case number	Age in years	GMFCS level	Description of functional skills
1	3	3	Ambulated with a walker at school; walked 8–10 steps independently before falling or reaching for a support; knee walked for 6–8 steps
2	8	1	Required upper extremity support to stand from half kneeling; knee walked 10 steps with one hand held; walked up two steps with same foot leading; walked down 2 steps with one foot leading inconsistently; walked 4–5 steps on a straight line, ¾ inches wide
3	2	3	Scooted on bottom for mobility; crawled in 4 point for 3–4 feet when verbally cued; independently stood for 1–3 seconds; walked with 2 hands held; utilized Kid-gait at home for ambulation
4	10	3	Used Loft strand crutches in community; walked between 6 soccer cones placed 2 feet apart in 16 seconds; walked up 4 steps alternating feet, inconsistently; lost balance when obstacles were in path during ambulation
5	3	1	Walked with hand-held assistance, taking steps independently but not directed towards a specific location; ambulated from waiting room at clinic to therapy room in 5–10 minutes with frequent stops; fell when changing surfaces during ambulation; pulled to stand at a support; reciprocally crawled
6	6	3	Bunny hopped for mobility; stood alone for 20 seconds; ambulated with hand held assistance

the other children received intervention 5 times a week. The family unit and the therapist determined the frequency of intervention. The physical therapists who provided the intervention were all NDTA certified in Pediatric Neuro-Developmental Treatment, with experience levels ranging from 15 to 41 years. The intervention followed the most recently adopted guidelines for NDT treatment (Biernan, Franjoine, Hazzard, Howle & Stamer, 2016). Parents filled out a questionnaire prior to the intensives to indicate their child's goals for the 3-week intensive along with medical history, behavioral concerns, and preferences for play. During the physical therapy examination, the therapists discussed the goals with the parents, and when appropriate, with the child. Goals were modified if necessary. A baseline GMFM-66 was performed. The GMFM is a criterion referenced tool that was developed specifically to assess intervention related change in children with cerebral palsy. The GMFM-66 is a shorter version which has demonstrated high reliability (ICCs = 0.97-0.99) (Russel, Avery, & Rosenbaum 2000, Shi, Wang, & Liao, 2006). The child's movement and postures were also assessed during functional movements. The therapists analyzed the child's potential for change and identified problems impeding goal attainment by using standardized testing (the GMFM), musculoskeletal assessment, movement analysis and clinical reasoning. Interventions were individualized for each child to allow the child as much initiation of posture and movement as possible. Repetition of part or whole task was performed as appropriate to assist with motor learning. Handling was utilized to perceive discrete sensorimotor responses and to assist the child in initiating, sustaining and terminating muscle activity, use more effective postures and movement synergies, grade movement and practice repetitive movements for strengthening, perceptual accuracy and motor learning. Depending on the child's stage of motor learning and quality of performance, handling may have been minimal or not used at all. Attendance of all children for the treatment sessions was 100%. A detailed description of each child's intervention program is provided in the Appendix. A YouTube video demonstrating a typical NDT session using current practice can be accessed at:https://youtube.com/watch?v=K8eepOPLjvQ

4. Description of the outcomes

Table 3 depicts GMFM scores prior to the intervention, immediately following the intensive intervention and 10 weeks to 3 months post intensive intervention conclusion, specific goals for the intervention, and success towards achieving those goals. Changes in GMFM scores immediately post intervention ranged from 0.9 to 4.2 with a mean change score of 3.15. The changes observed for all children immediately post intervention were well above the number needed for a minimum clinically important difference (MCID) of large effect size. (Oeffinger, Bagley, Roger, 2008). Oeffinger et al. defined MCID as "the magnitude of change required for an observable difference in function." A large effect size was defined as a grossly observable change in function.

Table 3
Description of Outcomes

Participant number	GMFM at initiation of intensive	GMFM at conclusion of intensive	GMFM 3 months post intensive	Goals for intervention	Achievement of goals
1	58.3	60.9	61.5	1. Walk forward 10 steps, turn 180 degrees and return 2. Walk forward 10 steps carrying a large object with two hands 3. Pick up an object from the floor, hands free, and return to standing	All goals achieved
2	71.7	75.3	76	1. Stand from half kneeling, hands free 2.Walk up 4 steps alternating feet without upper extremity support 3.Walk 10 steps on a ¾ inch line	All goals achieved
3	45	49.2	51.9	1.Stand alone for 10 seconds 2.Cruise for 5 steps to the left and right 3.Take 10 steps independently	1.Goal achieved and beyond – able to stand alone for 20 seconds 2.Goal partially achieved- able to cruise 5 steps to left and 3 to right 3.Goal not achieved; however, participant began using the reverse walker to take steps without assistance at home
4	71.2	72.2	72.2	1.Walk between 6 soccer cones placed 2 feet apart in 10 seconds 2.Walk up 4 steps alternating feet independently 3.Step over three 3 inch obstacles without losing balance	1.Partially achieved – able to complete task in 12 seconds 2&3 Achieved
5	53.6	57.6	63	1.Initiate standing from the floor using quadruped, kneeling and half kneeling as transitional postures, hands free 2.Increase walking speed as evidenced by ability to walk from waiting room to therapy room in 2 minutes	1.Goal partially achieved- participant required light touch from therapist to achieve this goal 2.Goal partially achieved- distraction appeared to be a limiting factor
6	49	52.1	53.1	1.Take 50 steps forward with verbal cues 2.Stand for 2 minutes independently	1.Goal partially achieved- able to take 35 steps forward independently 2.Goal partially achieved-able to stand alone for 1 minute

Changes 10 weeks to 3 months following the termination of the intervention ranged from 0 to 5.1 with a mean change of 1.67. No child regressed in GMFM scores following termination of the intense intervention. All of the children made progress towards their goals with some children achieving all of their goals.

Therapists' Comments: In a de-briefing after the completion of the 3 weeks, the therapists all reported that the intensives were stressful and exhausting but also exhilarating. All therapists were ready to provide this intervention again in the future as they believed it was to their patient's benefit. Direct comments included:

"I loved the ability to focus on the child and the goals; the outcomes and progress were exciting."

"It was good to see how excited and invested the parents were during the 3 week intensives."

Caregiver Comments: All of the parents were impressed with their child's progress. Direct comments included:

"Our child has been happier since the intensives because of her increased independence – she is less frustrated."

"The progress we saw during the intensives was motivating. We want to keep pressing on and it's reinvigorating when we see that much improvement."

"I loved it because it took some of the burden off at home since we knew he was getting everything he needed at the therapy center. We did not have to spend time on exercises at home."

5. Discussion

This study supports emerging research regarding the effectiveness of intensive intervention for children with movement disorders. Park reported that intensive therapy (3–11 times per week) resulted in better functional outcomes than conventional therapy (1- 2 times per week) for children with cerebral palsy

(Park, 2016). Studies specific to NDT interventions also support intensive intervention over conventional dosing (Tsorlakis, Evaggelinou & Tsorbatzoudix, 2004), (Lee, Park,& Lee, 2017).

Child's age and GMFCS levels were associated with outcome. Younger children made the most progress, consistent with a meta-analysis by Arpino et al. (Arpino, Fenicia, & De Luca, 1995). Children with lower GMFCS levels and/or medical conditions such as seizures showed less progress. This finding was similar to that reported by Hong et al. (Hong, Jo, Kim, Lim &Bae, 2017).

All of the children made progress towards their goals with some children achieving all of their goals. Current NDT theory is focused on setting individual goals. In this study, the therapists and family unit set 2–4 goals which were the focus of therapy. This finding concurs with a study by Bower et al. that demonstrated that the factor most strongly associated with increased motor skill acquisition was the use of specific measurable goals (Bower, NcLellan, Arney & Cambell, 1996).

Improvements noted during the intensive may also be related to a decrease of external daily demands such as school (intensives were performed during summer holiday) and increased focus and attention on the child by the caregivers regarding rest and nutrition as they were highly motivated to get the best possible outcome from the 3 week intensives. The therapists were also highly motivated to achieve good outcomes and did not spend therapy time performing formal reassessments for insurance, assessing orthotics and other equipment, or addressing new parental concerns related to recently identified limitations. The focus was on the pre-identified goals. Additionally, attendance for all of the children was 100%. The frequency and duration of this study may have been ideal. Previous studies found that longer duration and/or greater frequency resulted in the children becoming fatigued and lead to increased absences (Trahan & Malouin, 2002).

It is unknown how the provision of OT and ST, each for an hour daily during the intensives, affected the results of this study. Standardized results for OT and ST at the conclusion of the study were not available.

6. Recommendations

This case series supports the use of the current model of NDT when providing an intensive therapy. Future studies should examine the effectiveness of intensive NDT on parameters specific to NDT intervention, such as quality of posture and movement when performing functional tasks. This may assist in the delineation of the results of NDT interventions versus interventions based on other philosophies. The role of OT and ST intervention simultaneously and the comparative outcomes of those interventions requires investigation. Finally, the current model supported by third party payors and therapists is not congruent with emerging research. Further study and advocacy is needed to ensure children receive the appropriate intensity of care in order to achieve their maximum functional potential.

Conflict of interest

None to report.

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Appendix: Description of the interventions

All facilitation techniques are described in detail in the book, *Facilitation Techniques Based on NDT Principles* by Lois Bly and Allison Whiteside on the page numbers indicated. Additional activities are also described for some of the clients.

Case #1

1. Rotation with extension-child on therapist's lap (p. 79–81)
2. Prone to side lying with lower extremity dissociation (p. 158–160)
3. Lateral righting reactions with sideward protective extension (p. 172–173)
4. Elongated side sitting to unilateral weight bearing (p.163- 164) and unilateral weight bearing to half kneeling (p. 165- 166)
5. Prone to sit on ball (p. 178–180)
6. Posterior weight shifts to bear standing with upper extremity weight bearing on raised surface (p. 200- 201)
7. Bear standing with forward progression on inclined bolster (p210- 211)
8. Kneeling to half-kneeling facilitation from the front (p. 236- 237)
9. Standing to sitting-small client (p. 270- 271)
10. Gait Forward Walking-Facilitation from pelvis and femurs (p. 287-288)

In addition to these facilitated activities intervention also included:

1. Walking on treadmill at 0.3 m.p.h. with facilitation of pelvic rotation in the transverse plane
2. Stepping up onto a 6-inch-high surface and maintaining balance with foot on raised surface for 5 seconds with minimal/guarding assistance
3. Walking up 12 three-inch-high steps using step-to pattern with intermittent/guarding assistance

Case #2

1. Bench sitting on ball; extension rotation to the floor p. 99–101
2. Diagonal weight shift; flexion rotation and extensor rotation p. 110–112
3. Rotation to prone; facilitated rotation to prone and back to sit p. 123–126
4. Unilateral weight bearing to half kneeling p. 165
5. Kneeling to side sit; therapist in front of child p. 222–223
6. Kneeling to half kneeling; facilitation from the front p. 236
7. Weight shifts in half kneel; anterior weight shift to standing p. 240–241

After preparation with these facilitation techniques the following independent activities using intermittent or verbal assistance were used:

1. Alternating feet going up 14- 6 inch stairs
2. Alternating feet in floor ladder placed on incline
3. Pushing weighted table with resistance while LE in runner's stretch
4. Practicing balance with one foot on raised surface, adding perturbations

Case #3

1. Rotation with extension, child on therapist's lap p. 79–81
2. Prone to side lying with lower extremity dissociation p. 158–160
3. Elongated side sitting to unilateral weight bearing p. 163–165
4. Unilateral weight bearing to elongated side sit p. 165
5. Unilateral weight bearing to half kneel p. 165–166
6. Bear standing; forward progression p. 210–212
7. Kneeling lateral weight shift to half kneeling p. 217–219
8. Kneeling to half kneeling; facilitation for the side p. 230–231
9. Kneeling to half kneeling; forward weight shift to stand (UE supported) p. 232–233
10. Standing to sitting-small client (p. 270–271)
11. Lateral weight shift; sidewards cruising (with UE support on table) p. 249–251
12. Symmetrical stance with face side rotation p. 261–262
13. Gait forward walking facilitation from pelvis and femurs p. 287–288

Walking 15–30 feet pushing small push toy weighted with extra 15 pounds

Case #4

1. Bench sitting on ball; extension rotation to the floor p. 99–101
2. Diagonal weight shift; flexion rotation and extensor rotation p. 110–112
3. Rotation to prone; facilitated rotation to prone and back to sit p. 124–126
4. Unilateral weight bearing to half kneeling p. 165
5. Kneeling to side sit; therapist in front of child p. 222–223
6. Kneeling to half kneeling; facilitation from the front p. 236
7. Weight shifts in half kneel; anterior weight shift to standing p. 240–241

After preparation with these facilitation techniques the following independent activities using intermittent or verbal assistance were used:

1. Alternating feet going up 4 six inch stairs
2. Pushing large ball with therapist adding resistance while LE in runner's stretch
3. Practicing balance with one foot on raised surface, adding perturbations
4. Walking backwards and sideways on treadmill at 0.4 m.p.h.
5. Carrying tray with items on it while placing feet on defined footsteps

Case #5

1. Lateral weight shifting in sitting with UE at 90 degrees p. 29
2. Sit to stand: anterior weight shift at the hips p. 71
3. Rotation with extension, child on therapist's lap p. 79
4. Anterior weight shift to stand p. 87
5. Lateral weight shifting to single leg stance; over elevated bolster both ends p. 97
6. Ball: Posterior weight shift for activation of flexors p. 105
7. Rotation to one leg stand for extension with rotation p. 114
8. Prone to side lying with LE dissociation p. 158
9. Unilateral weight bearing to ½ kneel off bolster p. 164
10. 3pt to weight bearing to bear standing; no shoes p. 201
11. Bear climbing up elevated bolster p. 211

In addition to these facilitated activities, intervention also included:

1. Walking 30 feet pushing small push toy weighted with extra 15 pounds
2. Stepping up onto a 4-inch-high surface and maintaining balance with foot on raised surface with UE anterior on the wall
3. Visual attention with downward gaze to the floor to pick up objects with bilateral UE and return to standing

Case #6

1. Lateral weight shifting in sitting with UE at 90 degrees p. 29
2. Bilateral UE abduction with traction in 90/90 sitting p. 32
3. Long sit to 5-month position to ½ kneel p. 55
4. Anterior weight shifts to stand p. 87
5. Rotation to one leg stand for extension with rotation p. 114
6. Lateral weight shift in quadruped p. 185
7. Prone to side lying with lower extremity dissociation p. 159
8. Kneeling to side sit; therapist in front of child p. 222
9. Gait Forward Walking-Facilitation from pelvis and femurs p. 287

In addition to these facilitated activities, intervention also included:

1. Ladder ascending/descending 5 rungs using sensory pad (tactile/visually stimulating) and M&Ms for rotation in step stance with UE reaching at the top/bottom.
2. Lateral cruising at the wall using sensory pads fixed to the wall for tactile feedback and direction for visual compensation x 10–20 feet in each direction

Bly, L., & Whiteside, A. (1997) *Facilitation Techniques Based on NDT Principles.* San Antonio, TX: Therapy Skill Builders