Accepted Manuscript

A Retrospective Outcomes Study Examining the Effect of Interactive Metronome on Hand Function

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PII: S0894-1130(15)00133-7

DOI: 10.1016/j.jht.2015.06.003

Reference: HANTHE 926

To appear in: *Journal of Hand Therapy*

Received Date: 26 August 2014

Revised Date: 28 May 2015

Accepted Date: 30 June 2015

Please cite this article as: Shank TM, Harron W, A Retrospective Outcomes Study Examining the Effect of Interactive Metronome on Hand Function, *Journal of Hand Therapy* (2015), doi: 10.1016/j.jht.2015.06.003.

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Abstract:

Interactive Metronome (IM, The Interactive Metronome Company, Sunrise, Florida, USA) is a computer-based modality marketed to rehabilitation professionals who want to improve outcomes in areas of coordination, motor skills, self-regulation behaviors, and cognitive skills. This retrospective study examined the efficacy of IM training on improving timing skills, hand function, and parental report of self-regulatory behaviors. Forty eight children with mixed motor and cognitive diagnoses completed an average of 14 one-hour training sessions over an average of 8.5 weeks in an outpatient setting. Each child was assessed before and after training with the **Interactive Metronome** Long Form Assessment, the Jebsen Taylor Test of Hand Function, and a parent questionnaire. All three measures improved with statistical significance despite participants having no direct skill training. These results suggest an intimate relationship between cognition and motor skills that has potential therapeutic value.

Level 4, Retrospective Case Series

Keywords: Interactive Metronome, Hand Function, Pediatric, Outcome Study, Cognition

Abstract

Interactive Metronome (IM, The Interactive Metronome Company, Sunrise, Florida, USA) is a computer-based modality marketed to rehabilitation professionals who want to improve outcomes in areas of coordination, motor skills, self-regulation behaviors, and cognitive skills. This retrospective study examined the efficacy of IM training on improving timing skills, hand function, and parental reports of self-regulatory behaviors. Forty-eight children with mixed motor and cognitive diagnoses completed an average of 14 one-hour training sessions over an average of 8.5 weeks in an outpatient setting. Each child was assessed before and after training with the IM Long Form Assessment, the Jebsen Taylor Test of Hand Function, and an IM parent questionnaire. All three measures improved with statistical significance despite participants having no direct skill training. These results suggest an intimate relationship between cognition and motor skills that has potential therapeutic value.

1.0 Background

Therapists have examined the impacts of numerous factors,[1-3] such as age, traumatic injury, and restricted range of motion, on hand function. The vast majority of published hand therapy research has examined the effects of conventional techniques on function, including early active motion protocols, total end range time, orthotic intervention, tendon gliding, and scar massage. [4-6]This research has begun to identify the physical measures that contribute to loss of hand function and treatments that efficiently facilitate the return of hand function. However, research on the cognitive, or “top-down”, aspects of hand rehabilitation is lacking. Some researchers in the neuroscience community, such as Martin Lotze[7], have suggested incorporating top-down approaches into the global hand therapy mentality.

One such modality that has grown popular with therapists is Interactive Metronome (IM, The Interactive Metronome Company, Sunrise, Florida, USA). **Interactive Metronome** is a computer program originally intended for improving musicians’ timing.[8]Later, the company promoted research on use of the IM as a sports-enhancement modality, marketing widely to occupational and physical therapists. Shortly after, the company published research suggesting that IM training improved academic and behavioral weaknesses in children with ADD/ADHD.[9] Improvements in language processing, reading skills, listening skills, aggression, and attention were demonstrated.[10-12] Many of these early studies also examined therapy with IM for motor skill improvement, but outcomes were inconclusive. Data collected from the Bruininks Oseretsky Test of Motor Proficiency, the Nine-Hole Peg Test, the Sensory Integration and Praxis Test, the Sensory Profile, and the Evaluation Tool of Children’s Handwriting have all shown inconsistent results.[13-15]More research is needed to clarify the impact of IM on motor skills.

Neal Alpiner presented an unpublished paper[16] at the 2004 National Physical Medicine and Rehabilitation Conference comparing a small cohort of seven participants with IM training to a control subject with no IM training. The participants were observed with functional magnetic resonance imaging (fMRI) performing a rhythmic motor task. The IM-trained participants had increased bilateral neuronal activity compared to the control. He concluded the increased activity may be a positive indication of neuroplasticity in both higher and lower brain centers. Researchers in Germany used positron emission tomography (PET) to identify distinct cortico-cerebellar networks activated by rhythmic motor synchronization and bimanual coordination tasks.[17] Similar studies have examined various aspects of temporal control and motor skills or cortico-cerebellar loops using imaging technologies like PET, fMRI, and magnetic electroencephalography.[18-19] These studies are demonstrating the link between cognition and movement. They repeatedly show that physical tasks activate/strengthen executive pathways and vice versa.

2.0 Purpose

We sought to determine: the extent to which IM training impacts functional hand skills, to which parents report an observable difference in behavior after IM training, and to which timing scores improve after IM training. This study was conducted as part of a continuous improvement project in a large outpatient rehabilitation center at a children's hospital.

3.0 Methods

3.1 Design

This retrospective case series study compared pre- and post-test data from three measures: 1) timing as measured by the IM Long Form Assessment (LFA),[15] hand function as measured by the Jebsen Taylor Test of Hand Function (JTTHF),[20] and behavior as measured by performance on an IM parent questionnaire.[15]

3.2 Data Collection

Data were collected via chart review of children receiving these services between January 1, 2012 and December 31, 2013. As standard of care, all therapists using this modality kept standardized paper logs of these data. All therapists were licensed occupational therapists, certified in use of IM, and trained in use of data-collection logs intended for outcome studies by the outpatient therapy department. Each therapist has also demonstrated competency in administering and interpreting all three measures used. Six therapists participated in this process. Twenty-two logs were reviewed from 2012 and 28 from 2013. Two logs from 2013 were not used because of incomplete data.

3.3 Privacy, Informed Consent, and Disclosures

This retrospective study was approved by the (Removed for review) Institutional Review Board. This study was unfunded. This author has no relationship with the Interactive Metronome Company to disclose, financial or otherwise**.**

3.4 Participants

A total of 48 children completed therapy and all pre- and post-therapy measures during this time period. All children were from the **mid-Atlantic** states and seeking outpatient occupational therapy treatment. **The average age of the participants was 9 years (range, 6-17 years; Figure 1).** Fourteen children were diagnosed with ADD/ADHD. Five **children** were diagnosed with c**erebral palsy** or h**emiplegia**. Nine **childre**n were diagnosed with a coordination disorder. Ten **children** were diagnosed with **pervasive developmental disorder or autism**. Five children had other rare neuromuscular disorders. Five children had neurologic conditions such as seizures or concussion. The sample consisted of 41 boys and 7 girls. This ratio seems to be grossly consistent with the overall prevalence of these diagnoses across sex.[21-22]

3.5 Instruments

Interactive Metronome is a computer program consisting of a software package and related hardware. The software generates a fixed reference beat at a frequency of 54 beats per minute. **The participant listens to this beat** via headphones or computer speakers. The participant is asked to activate a trigger on the beat for a duration determined by the therapist. The software then gives both auditory and visual feedback relating how many milliseconds before or after the beat activation occurred. The triggers (hardware) **plug** into the computer port and consist of round buttons (one is about 3" in diameter, the other is about 6" in diameter) and foot plates (a flat pad on the floor about 6" by 18").

For assessment purposes, the IM software comes with its own outcome measure, **the LFA**. This assessment measures the participant's timing in activating the trigger to the beat over 14 different tasks lasting less than one minute each. A description of the tasks/exercises can be found online, but in general they include: hand clapping, hand tapping on dominant and non-dominant sides, toe tapping, heel tapping, balance, and alternating upper- and lower-body trigger activation. A very light strike of the trigger is all that is needed to activate a response. At the completion of all **14** exercises, the software generates a score, which is an average of the performance on each of the **14** individual tasks. The LFA can be completed easily in one treatment session**,** even if rest breaks are needed between tasks. Each participant was asked to complete this assessment prior to training and then again on their last treatment session. Better performance is represented by a lower score in milliseconds. Internal reliability between diagnostic items was **reported at 0.89 .**[23]

The JTTHF, a standardized, norm-referenced test that measures the time it takes to complete several skilled tasks, was administered to each participant as the outcome measure for global hand functioning. Participants completed this assessment prior to IM training and again within one week of their last IM training session .These tasks include card flipping, small object manipulation and placement, simulated eating, checker stacking, and empty and full can placement.[20] The JTTHF has long established reliability and validity and continues to be widely used in research.[24-30] Similar to the LFA, a faster timing score (lower) represents superior performance.

The IM Company developed the parent questionnaire to assist therapists in assessing change in behavior. It consists of 12 questions rated on a 5-point Likert scale (1 = most of the time, 2 = frequently, 3 = occasionally, 4 = seldom, 5 = never). It explores a range of behaviors including: enjoys and fully interacts in peer relationships, speaks fluidly without stuttering, keeps beat with music, reads and responds to social cues, remembers information, can focus and follow through on a variety of tasks, is well coordinated, and can regulate and control activity level and behavior. **A lower score indicates better performance. The best possible score is 12, and the worst possible score is 60**. **This questionnaire was completed at the same time as the LFA, before the first and after the last IM session**.

3.6 Procedure

Prior to beginning IM-focused therapy, each participant completed **the previously described** JTTHF and LFA measures in a quiet room alone with the therapist. The parent typically completed the questionnaire in the therapy waiting room.

Following testing, subsequent treatment sessions consisted of completing as many repetitions of IM exercises as the child could tolerate during one hour. **The therapist used her own judgment about the** child's skills and endurance to determine the difficulty levels and types of exercises prescribed to activate the triggers. **For example, simple exercises like hand tapping on a trigger and clapping hands together (where the trigger is worn on a hand strap) are often used to introduce the program to children and also for longer endurance tasks**. The exercises were all simple gross motor movements with a light tap to activate the trigger; there were no exercises requiring or aimed at improving hand dexterity.

Children were asked to complete two **one-hour** sessions per week for a total of 12-15 sessions. In this group of patients, the average number of treatment sessions was 14.4 **(range, 10-15 sessions**) occurring over an average of 8.5 weeks (range 6-12weeks). **The number of trigger activations (repetitions) during the course of training ranged from 8088 to 31692**. The average number of repetitions completed was 16297. **Again, the broad range reflects the individualized treatment for each child's abilities; we believe this represents best practice**.

Upon finishing the training as described above, each participant was retested with the LFA and the JTTHF and parents were asked to fill out the same questionnaire reflecting the child's recent behavior.

3.7 Data Analysis

Descriptive statistics were used to describe the study participants and the course of treatment (means, modes, ranges). Percent improvements were calculated for each pre/post-test set of data. In addition, change in performance on individual items on the JTTHF and the parent questionnaires were reviewed for patterns of interest. Paired *t*-tests were computed on each set of pre- and post-test data. Pearson correlation coefficients were calculated to look for relationships between age and percent improvement and number of repetitions completed and percent improvement.

4.0 Results

4.1 Timing Scores:

The average adjusted LFA pre-test score in this population was 212 milliseconds **(median, 225; range, 53-403).** The average adjusted LFA post-test score was 76 milliseconds (median, 57; range, 22-293). This is a **64**% improvement in timing scores (SE, 3%). A paired two-sample Student *t*-test demonstrated that the pre/post-test change on average IM timing scores was statistically significant ($P < 0.0001$).

The IM company provides the norms chart shown in Table 1 to describe what the scores mean. Using the norms provided, **Figure 2 shows the number of participants who moved to a higher level performance category**. Ninety percent of the sample demonstrated below average timing skills prior to training. **After training, only 27% had below average timing and 73% had average timing or better**.

Statistical analysis shows no relationship between percent improvement and number of repetitions completed (Pearson correlation coefficient, $r = 0.33$).

No relationship was found between age and percent improvement on the LFA (Pearson correlation coefficient, $r = 0.06$).

4.2 Hand Function Scores:

The JTTHF data showed statistically significant change in performance for both the dominant hand and the non-dominant hand from pre- to post-test ($P < 0.0001$). This was calculated using a two-sample paired *t*-test. Figure 3 depicts the change in performance from pre- to post-test based on age- and sex-based norms for the JTTHF total score. Prior to IM training, 64% of the children fell below average norms with their dominant hands and 69% were **below average in hand skills with their non-dominant hand. After the training, 76% of children were average or above average in dominant hand skills, and 62% were above average or average in non-dominant hand skills.**

Figure 4 is a graphic representation of the change in performance over time on each subtest of the JTTHF using the dominant hand and non-dominant hand.

4.3 Parent Questionnaire Scores:

The average pre-test score was 34, and the average post-test score was 25. This represents a 26% improvement on observed behaviors. A paired two-sample *t*-test indicated that this change was statistically significant ($P < 0.0001$).

5.0 Discussion

The results of this outcomes study suggest the following: 1) a short regimen **of therapist-led** IM training is likely to significantly, positively change functional hand skill in a pediatric population as measured by the JTTHF; 2) a short regimen is likely to significantly, positively change a participant's internal timing abilities; and 3) parents report statistically significant changes in a variety of their children's behaviors after IM training. To validate the results, this study should be replicated with a prospective design, but these results suggest that cognitive interventions can improve hand function in some populations.

These data supported the efficacy of IM training on timing skills. This has been repeated in many studies. It was exciting to see, however, that these outcomes showed a 64% improvement because the participants in therapy at this setting are typically more impaired than those described in other studies. The IM Company itself published a study demonstrating a 67% increase in timing with a population of adolescents.[30] In this sample, 47 out of 48 participants showed improvement in their timing after training. These data did not reveal a relationship between improvement and the number of repetitions completed, and our patients completed far less repetitions than other studies have reported. The threshold of repetitions for maximum efficacy and longevity is unclear. The younger participants did not make faster or greater gains compared to the older participants, which was a bit surprising given the long-held assumption that the brain is more plastic in children younger than nine years.

The results of the JTTHF were particularly interesting. The changes in non-dominant hand function are more pronounced and equitable across tasks. Perhaps this pattern is a reflection of improved neural efficiency or organization. The non-dominant hand is less experienced for many of these tasks, so it made sense that the improvements were more noticeable and more equivalent across tasks. The changes were immediately noticeable to the children and their families, and some children were even surprised by their own gains.

The results of the parent questionnaire largely supported therapists' observations of change in behavior as well as parents' prior reports. The greatest areas of change were coordination, speech fluency, and keeping a beat. These are consistent with previous studies.[7,9,10,12,13, 30]

Philosophically, the use of intervention tools from a variety of domains makes sense using dynamic systems theory. **Interactive Metronome** is unique in that it gives immediate unbiased, nonjudgmental visual and auditory feedback on a participant's motor performance over thousands of repetitions. Most participants find it challenging, like a game, as opposed to critical, like feedback from a parent or therapist. **As therapists we believe that the child's internal motivation, parental support, environment, and the therapist's unique skills in creating a positive rehabilitation experience are all key ingredients to the success of this program.**

Scientifically, these results are consistent with two particular studies recently published in neurorehabilitation journals. Yozbatiran et al. published a single case study describing the effects of robotic training on arm function after spinal cord injury. Interestingly improvements were only found in the non-dominant arm and hand.[28] Similarly Boggio et al. studied the effects of transcranial direct current stimulation on hand function. They reported significant results were only found in the non-dominant hand. They hypothesized that there could be greater neuroplasticity related to the underuse of the non-dominant hand.[25]This study offers a consistent profile of results across each item of the JTTHF with the non-dominant hand. The opportunities for research following this lead are wide open.

In addition, rehabilitation therapists working in pain management are pioneering the use of cognitive techniques. Fedorczyk and Barbe briefly discusses the role of behavior modification, education and psychological interventions as part of the plan of care in treating hand therapy patients with centralized pain.[31] Many others promote the use of graded motor imagery for pain-management particularly pain affecting the hand. Unlike traditional therapy interventions, motor imagery provides visual cues and proprioceptive input to affect somatosensory reorganization in the brain.[32-33] The hope is that by assisting the creation of new pathways in the brain improved hand function will follow. Similarly, orthopedic surgeon David Ring has written extensively on using cognitive-behavioral techniques to influence positive functional outcomes after traumatic hand injury.[34-35] It has become clear that there are seemingly endless loops of communication between brain structures smudging the lines between cognition and movement. Leisman and Melillo discuss the dual role of motor and nonmotor regulation involving the cerebellum and the basal ganglia.[11] They wrote, “It is thought that cognitive function, or what we call thinking, is the internalization of movement and that cognition and movement are really the same.” It is essential that hand therapists engage in neurorehabilitation based studies so that we can include a greater variety of efficacious treatments in our armamentarium.

5.1 Limitations

Retrospective studies are always limited by nature of design. Specifically, in this study, there were limitations that perhaps could be avoided in the future. Each therapist scored both the pre-tests and the post-tests of the child they were treating. This may have introduced bias; however, this was not set up as a prospective study. Blind testers obviously would have been preferable. In our outpatient therapy department, these outcome measures help delineate best practice; there are no external rewards or incentives for submitting better test scores. In addition, we had concerns that the JTTHF was not able to capture the quality of movement. While speed or fluidity of movement is an important part of dexterity, suggesting automaticity (despite lack of repetitive training for the task), in some cases participants scored worse (slower) on the post-test than they did on the pre-test. In most of these cases, therapists made observations that the quality of movement was notably improved despite the slower score. We have no way of capturing these data. In the past we have used videotaping; however, we have not developed a scale to help us quantify what we are seeing. In the future, we plan to use the Bruininks

Oseretsky Test of Motor Proficiency (BOT-2) with added scales for observable quality of movement ratings.

Similarly, the behavioral questionnaire used during this time period had questions that included more than one performance area and therefore lacked some validity. A new questionnaire based on therapist and parent feedback is now in use. Lastly, we collected no data on how long these effects last. Parent feedback suggests these are permanent results, but this has not been substantiated with any research. In the future we would also like to collect data longitudinally.

6.0 Conclusion

This study supports the notion that a cognitively based modality such as Interactive Metronome can produce significant changes in the quality of motor skills of the hand. In the sample of 48 children we examined, the average JTTHF score significantly improved after IM training. Both the dominant hand and the non-dominant hand improved. Although the improvement percentage was greater in the dominant hand, improvements were more equitable across tasks with the non-dominant hand. These patterns of improvement are consistent with findings in recent neuroscience studies.

Acknowledgements

I would like to thank Wendy Haron, OTR/L first and foremost as she worked for so long creating this program and making such a difference in the lives of all the children she treated. She was the vision behind this study. Thank you to Patty Hove, Amy Jackson, Martina Brennan, Isabel Meuller, and Alyssa Paranto for their wonderful clinical skills and dedication to this program. I would also like the thank Sherlly Xie and the Department of Biomedical Research at (removed for review) who assisted me in data analysis and editing. I would also like to thank Dr. Kevin Lutsky and Adam Udell for their editorial assistance.

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Figure Legends:

Figure 1. The age distribution of the participants

Figure 2. Number of participants in each norm category for timing prior to training and after training

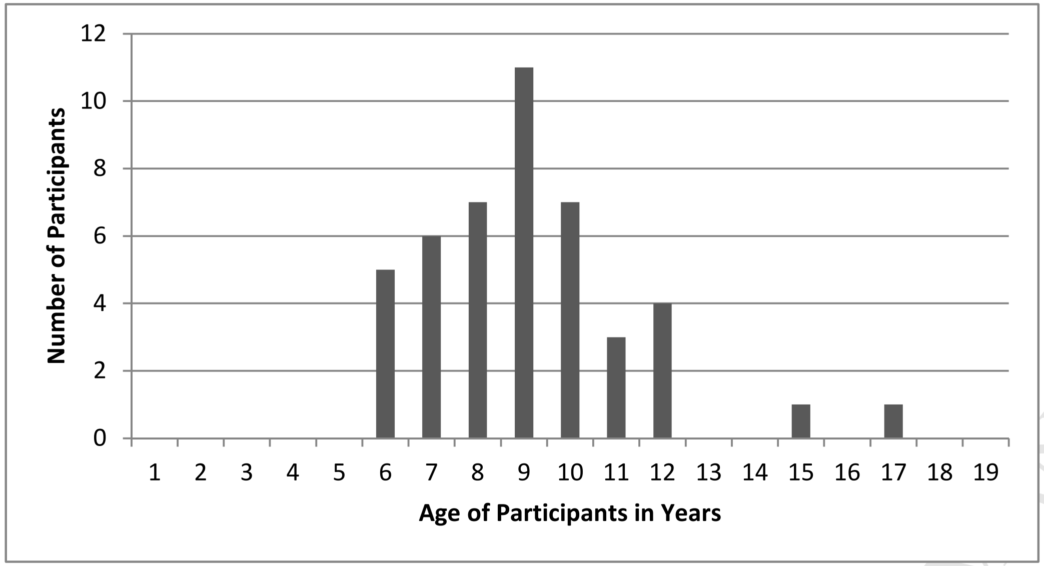
Figure 3. Performance on JTTHF pre- and post-therapy based on age- and sex-based norms

Figure 4. Percent improvements on JTTHF using each hand

Table 1: Descriptive Norms for Timing Scores on the Interactive Metronome Long Form Assessment[12]

Age	6 years	7-8 years	9-10 years	11-12 years	13-15 years	16+ years
Extreme Deficiency	280+	270+	260+	240+	215+	200+
Severe Deficiency	175-279	170-269	160-259	155-239	150-214	147-199
Below Average	120-174	90-169	80-159	75-154	72-149	70-146
Average	90-119	65-89	55-79	45-74	42-71	41-69
Above Average	56-89	45-64	38-54	36-44	33-42	30-40
Exceptional	40-55	32-44	22-37	26-35	23-32	22-29
Superior	Below 40	Below 32	Below 28	Below 26	Below23	Below 22

Numbers represent the average number of milliseconds that the trigger was activated either before or after the beat. Lower scores represent superior function.


12
10
8
6
4
2
0
Number of Participants
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Age of Participants in Years

6	1	0
6	2	0
6	3	0
6	4	0
6.5	5	0
7	6	5
7	7	6
7	8	7
7	9	11
7	10	7
7	11	3
8	12	4
8	13	0
8	14	0
8	15	1
8	16	0
8	17	1
8	18	0
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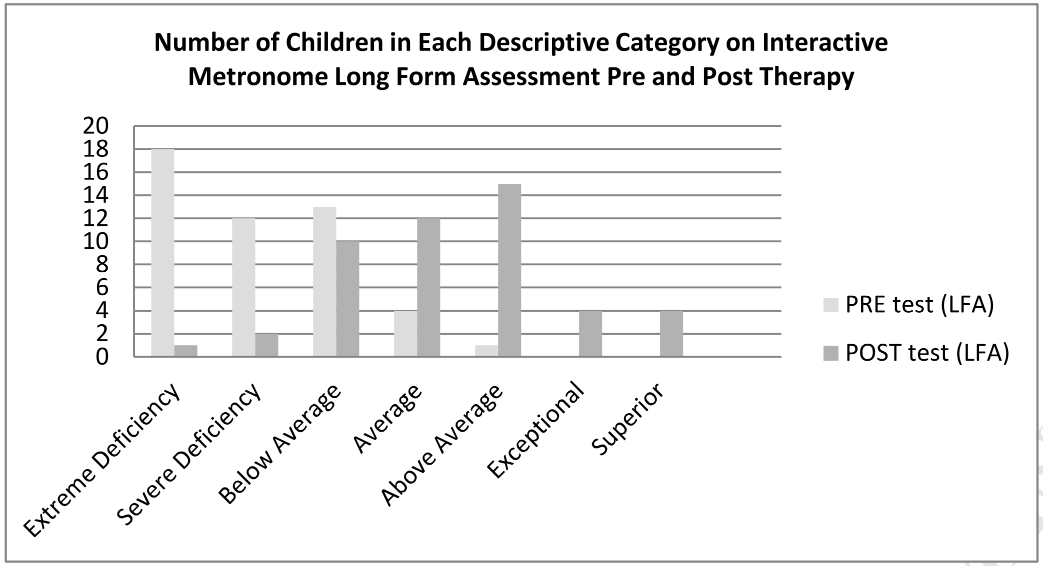
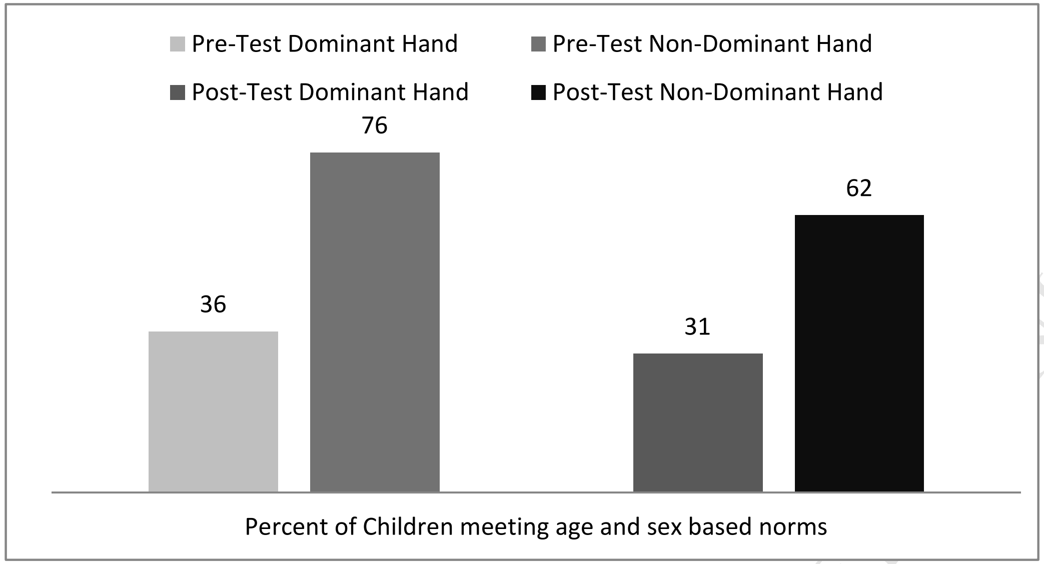


Number of Children in Each Descriptive Category on Interactive Metronome Long Form Assessment Pre and Post Therapy
20
18
16
14
12
10
8
6
4
2
0
Extreme Deficiency
Severe Deficiency
Below Average
Average
Above Average
Exceptional
Superior
PRE test (LFA)
POST test (LFA)

Category	# in cat at pre test	#in cat at POSt test
Extreme De	18	1
Severe Def	12	2
Below Aver	13	10
Average	4	12
Above Aver	1	15
Exceptiona	0	4
Superior	0	4

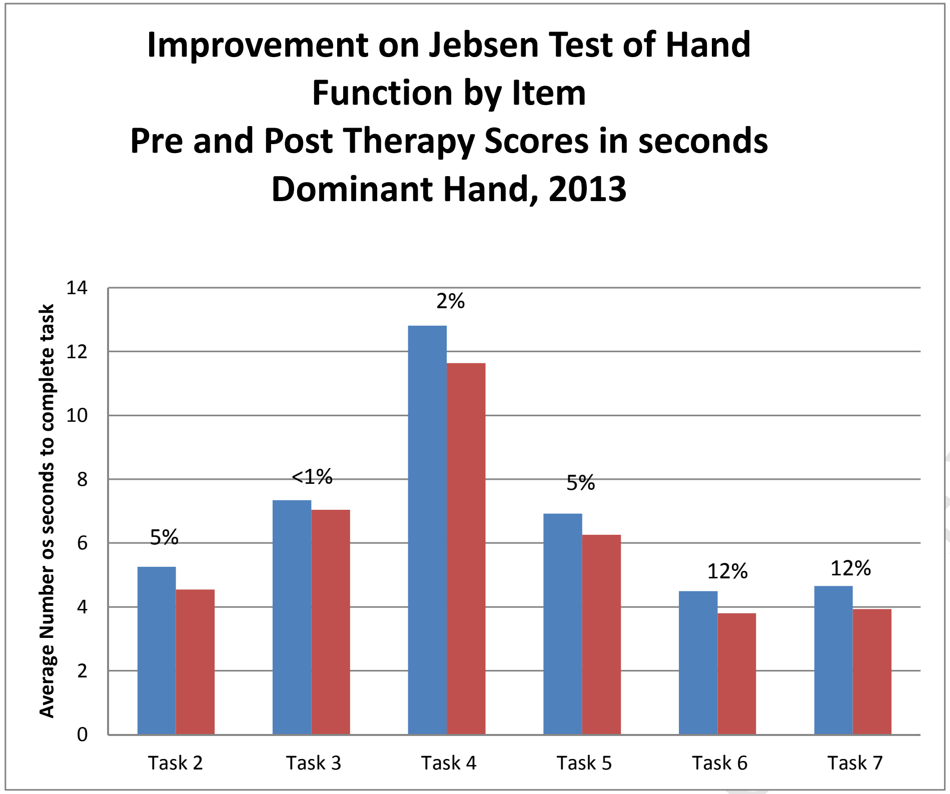
Category		
Extreme De	18	1
Severe Def	12	2
Below Aver	13	10
Average	4	12
Above Aver	1	15
Exceptiona	0	4
Superior	0	4

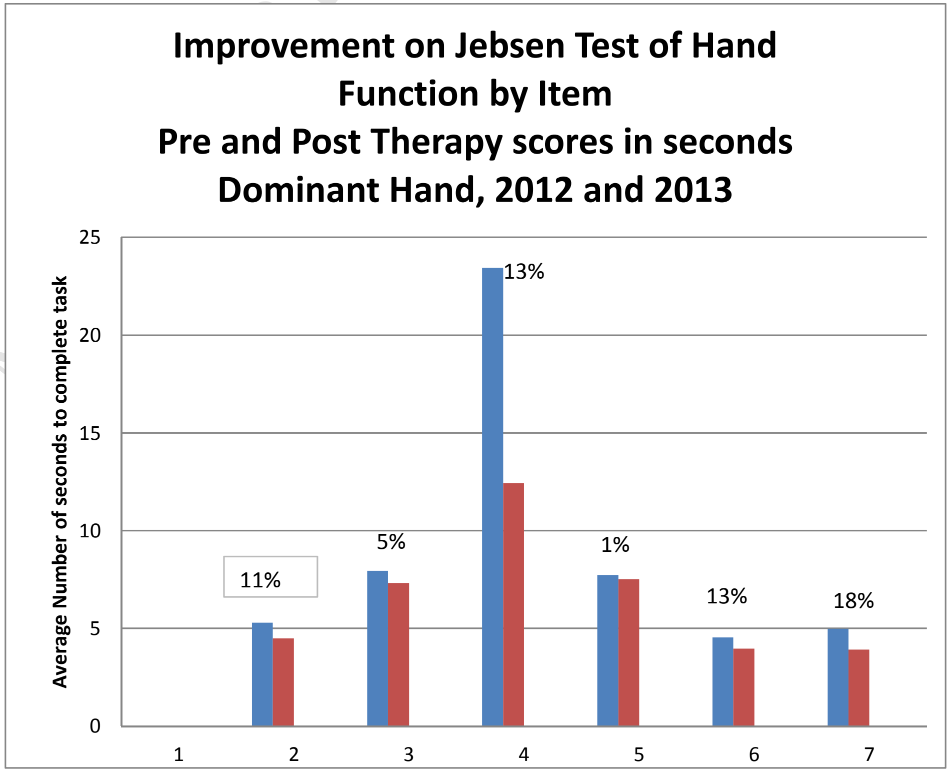

Pre-Test Dominant Hand
Pre-Test Non-Dominant Hand
Post-Test Dominant Hand
Post-Test Non-Dominant Hand
76
62
36
31
Percent of Children meeting age and sex based norms

#2D pre	#2D post	%change	#2NDpre	#2NDpost		#3DPre	#3Dpost		#3NDpre	#3NDpost		#4Dpre	#4Dpost		#4NDpre	#4ND post		#5Dpre	#5Dpost		#5NDpre	#5NDpost		#6Dpre	#6Dpost		#6NDpre	#6NDpost		#7Dpre	#7Dpost		#7NDpre	#7NDpost		age	gender	TD pre	TD post	TND pre	ND post
6.7	6.7	0%	10.3	9	13%	11	10.4	5%	13.8	16	-16%	40	25.8	36%	40	22	45%	9.7	12.1	-25%	17.7	10.2	42%	7.8	7	10%	12.5	7.4	41%	10.3	8.1	21%	16	7.5	53%	6	1	85.5	70.1	110.3	72.1
4.33	3.7	15%	3.84	3.63	5%	8.73	10.68	-22%	8.59	8.45	2%	8.8	14.25	-62%	16.62	18.65	-12%	11.24	10.4	7%	8.1	11.45	-41%	5.72	3	48%	4.26	4.47	-5%	4.26	3.91	8%	6.84	4.61	33%	6	1	43.08	45.94	48.25	51.26
6.9	7.8	-13%	6.8	5.8	15%	8.9	13.7	-54%	10.7	10.8	-1%	7.8	28.2	-262%	10.8	15.4	-43%	10	9.3	7%	19.7	12.6	36%	9.7	8.7	10%	10.7	9.1	15%	8.8	7.9	10%	11.2	8.7	22%	6	1	52.1	75.6	69.9	62.4
5	3	40%	15	3	80%	12	6	50%	15	6	60%	49	23	53%	94	37	61%	5	3	40%	11	7	36%	6	3	50%	6	7	-17%	9	4	56%	9	5	44%	7	1	86	42	150	65
5	5	0%	7	6	14%	10	6	40%	8	5	38%	15	12	20%	17	11	35%	14	6	57%	8	7	13%	4	4	0%	4	4	0%	5	3	40%	5	4	20%	7	1	53	36	49	37
6	5	17%	7	5	29%	10	6	40%	8	7	13%	43	11	74%	23	17	26%	4	4	0%	8	7	13%	5	3	40%	5	4	20%	7	4	43%	5	4	20%	7	1	75	33	56	44
5.01	5.6	-12%	4.77	5.3	-11%	7.61	7.3	4%	7.76	8.3	-7%	12.69	11	13%	19.62	10.8	45%	6.77	5.3	22%	5.97	5.3	11%	4.54	3.7	19%	4.49	4.1	9%	4.66	3.7	21%	5.19	4.7	9%	7	1	41.28	36.6	47.8	38.5
4	3.6	10%	4	5	-25%	7	7.2	-3%	10	10.5	-5%	13	8.6	34%	22	10.8	51%	8.14	4.7	42%	8.27	5.5	33%	5.42	4.2	23%	6.3	5.3	16%	4.42	4.9	-11%	5.89	6.2	-5%	8	1	41.98	33.2	56.46	43.3
6	4	33%	7	3	57%	7	5	29%	6	5	17%	19	9	53%	10	13	-30%	4	10	-150%	16	8	50%	3	2	33%	3	2	33%	3	2	33%	3	2	33%	8	1	42	32	45	33
5.09	4.8	6%	6.4	5.3	17%	9.5	7.12	25%	10.54	8.38	20%	13.65	15.36	-13%	19.9	20.18	-1%	9.5	8.03	15%	7.54	8.31	-10%	4.54	2.79	39%	6.35	3.28	48%	4.12	4.19	-2%	5.58	4.33	22%	8	1	46.4	42.29	56.31	49.78
15.2	6.3	59%	10.3	8.4	18%	6.9	9.5	-38%	8.5	8.4	1%	14.8	21.9	-48%	26.8	31.6	-18%	7	9.4	-34%	8.58	7.9	8%	4.1	3.8	7%	4.5	3.5	22%	4.2	3.1	26%	3.9	3.8	3%	8	1	52.2	54	62.58	63.6
4.33	3.17	27%	8.27	4.17	50%	7.48	6.56	12%	10.14	8.36	18%	23.9	8.2	66%	21.9	9.86	55%	4.3	3.5	19%	9	7	22%	4.2	3.27	22%	5.2	2.89	44%	5.3	2.83	47%	5.6	4.23	24%	8	1	49.51	27.53	60.11	36.51
6.7	5.5	18%	6.5	6.5	0%	7.2	5.9	18%	7	5	29%	10.3	7	32%	15	10.5	30%	15.9	4.5	72%	6.4	6	6%	4.4	4.3	2%	4.7	4.7	0%	4.2	4	5%	4.4	5	-14%	8	1	48.7	31.2	44	37.7
4	4	0%	8	3	63%	7	5	29%	7	5	29%	9	8	11%	53	8	85%	13	8	38%	30	4	87%	3	3	0%	5	3	40%	4	2	50%	4	2	50%	9	1	40	30	107	25
7.1	9	-27%	10	5	50%	10	10	0%	10.3	9	13%	10.1	9	11%	13	9	31%	7.3	13	-78%	8.2	10	-22%	5.1	5	2%	5.8	4	31%	5	5	0%	5.9	4	32%	9	1	44.6	51	53.2	41
5	3	40%	4	3	25%	8	7	13%	9	6	33%	9	8	11%	17	12	29%	6	7	-17%	9	4	56%	3	2	33%	5	2	60%	5	2	60%	5	3	40%	9	1	36	29	49	30
7	5	29%	6	5	17%	8	9	-13%	8	8	0%	25	13	48%	30	37	-23%	10	9	10%	10	6	40%	5	3	40%	6	4	33%	4	3	25%	6	4	33%	9	1	59	42	66	64
6.5	8.4	-29%	12.5	12.8	-2%	16	19	-19%	14.5	25	-72%	85	28.5	66%	48	31.7	34%	25	41	-64%	20	35	-75%	9	12.8	-42%	18	10	44%	11	8.8	20%	15	15	0%	9	1	152.5	118.5	128	129.5
4.12	3.05	26%	4.68	3.59	23%	10.89	7.63	30%	7.96	8.08	-2%	12.08	9.58	21%	21.65	20.01	8%	6.91	9.3	-35%	4.96	13.11	-164%	3.77	3.86	-2%	3.63	3.01	17%	3.91	3.52	10%	3.91	3.1	21%	9	1	41.68	36.94	46.79	50.9
3.4	4.7	-38%	3.6	4.3	-19%	5.3	5.2	2%	6.8	8.1	-19%	20.5	14.4	30%	17	12.8	25%	6.7	6.9	-3%	10.4	5.6	46%	3.8	3	21%	4.3	3.5	19%	4.5	4.2	7%	4	3.6	10%	9	1	44.2	38.4	46.1	37.9
6.95	6.98	0%	9.92	7.63	23%	6.23	6.98	-12%	7.22	8.17	-13%	9.96	9.01	10%	13.98	9.71	31%	9.33	10.4	-11%	11.2	9.08	19%	7.92	3.98	50%	5.95	4.4	26%	8.58	3.63	58%	6.55	3.84	41%	9	1	48.97	40.98	54.82	42.83
2	4.6	-130%	3	4.6	-53%	6	8	-33%	6	7	-17%	12	6.8	43%	17	9	47%	6	7	-17%	5	6	-20%	3	4	-33%	3	4.2	-40%	3	4	-33%	3	3.5	-17%	9	1	32	34.4	37	34.3
5.1	3.52	31%	4.5	6.05	-34%	7	6.3	10%	5.3	6.92	-31%	14.7	10.45	29%	11.4	9.45	17%	5.6	6.39	-14%	4.8	7.9	-65%	3.7	3.37	9%	3.6	3.8	-6%	4.1	3.6	12%	4.4	4.4	0%	10	1	40.2	33.63	34	38.52
4.4	4.4	0%	5	5.6	-12%	5.5	9.3	-69%	6.5	4.9	25%	6.9	10.1	-46%	9.4	16	-70%	4.9	7.9	-61%	5.3	7.2	-36%	3.3	2.8	15%	3.3	3.3	0%	3.3	2.7	18%	3.7	3.4	8%	10	1	28.3	37.2	33.2	40.4
8	4	50%	4	4	0%	8	7	13%	10	5	50%	14	10	29%	14	12	14%	9	6	33%	5	2	60%	7	4	43%	5	3	40%	7	3	57%	7	4	43%	10	1	53	34	45	30
4	4.2	-5%	5.3	4.1	23%	10	5.9	41%	6.9	4.5	35%	7.9	10.4	-32%	12.4	11.2	10%	4.1	3.6	12%	9	3	67%	2.8	3	-7%	3	2.6	13%	2.9	3.2	-10%	3.5	2.9	17%	10	1	31.7	30.3	40.1	28.3
3.63	3.2	12%	3.98	2.7	32%	6	5.9	2%	6	5.9	2%	15.71	7.5	52%	11.45	9.3	19%	5.03	5	1%	8.49	6.5	23%	3.14	3.4	-8%	3.84	3.1	19%	3.35	4.4	-31%	2.44	3.5	-43%	10	1	36.86	29.4	36.2	31
8.1	4.5	44%	5.4	7.8	-44%	7.1	5.4	24%	6.7	6	10%	14.7	11	25%	27.8	14.5	48%	8.3	7.7	7%	12.5	8.8	30%	5.4	5.3	2%	4.4	5.2	-18%	5.3	4.6	13%	6.5	5	23%	10	1	48.9	38.5	63.3	47.3
3.42	3.21	6%	2.86	3.28	-15%	6.07	6.77	-12%	6.21	7.54	-21%	7.4	10.61	-43%	10.12	12.5	-24%	6	5.4	10%	8.02	5.6	30%	4.33	3.49	19%	3.98	3.4	15%	5.79	4.19	28%	5.17	3.98	23%	11	1	33.01	33.67	36.36	36.3
3.5	2.5	29%	4	2.4	40%	5	3.9	22%	4.8	3.9	19%	8	7.4	8%	9	9.1	-1%	2.9	3.4	-17%	3.5	4	-14%	3	3.1	-3%	3.5	3	14%	3.1	3	3%	3	3.3	-10%	11	1	25.5	23.3	27.8	25.7
6	5	17%	6	7	-17%	9	12	-33%	15	15	0%	300	34	89%				20	20	0%	38		100%	6	12	-100%	9	6	33%	6	9	-50%	8	7	13%	12	1	347	92	76	35
4	3.9	3%	50	25	50%	5	8	-60%	25	20.2	19%	12	9	25%	27	25	7%	4	3.9	3%	20	12	40%	4	3.9	3%	13	12	8%	4	4	0%				12	1	33	32.7	135	94.2
4.4	4.2	5%	5.7	4.7	18%	7.6	6.8	11%	7.8	8.3	-6%	9.9	14.2	-43%	16.2	9.9	39%	5.2	7	-35%	5.4	8.4	-56%	3.8	3.4	11%	4.6	4.1	11%	4.7	4.5	4%	4.4	4.3	2%	12	1	35.6	40.1	44.1	39.7
4.14	3.36	19%	5.31	3.52	34%	8.77	6.27	29%	11.97	7.83	35%	11.04	8.89	19%	13.11	12.67	3%	6.32	5.36	15%	11.04	5.42	51%	3.84	3.67	4%	4.27	4.19	2%	4.31	3.5	19%	4.61	4.2	9%	12	1	38.42	31.05	50.31	37.83
4	3.6	10%	4.1	4.1	0%	6	6.7	-12%	7	6.1	13%	21	7.7	63%	15	11.1	26%	4.5	3.7	18%	5	3.4	32%	3.9	2.9	26%	4	3.1	23%	4	2.9	28%	4	3.5	13%	12	1	43.4	27.5	39.1	31.3
3	2	33%	3	2	33%	5	4	20%	5	5	0%	6	6	0%	7	6	14%	5	2	60%	4	2	50%	2	1	50%	3	2	33%	2	1	50%	3	1	67%	17	1	23	16	25	18
5	3	40%	5	3	40%	7	5	29%	7	7	0%	24	14	42%	25	17	32%	7	6	14%	12	8	33%	3	3	0%	3	3	0%	5	3	40%	4	3	25%	6	2	51	34	56	41
5	6.3	-26%	6	5.5	8%	8.7	6.5	25%	8.2	7	15%	13.5	6.5	52%	12.8	5.8	55%	5	6	-20%	5	7	-40%	4	3.8	5%	4.2	4.2	0%	4.5	3.2	29%	5	5	0%	6	2	40.7	32.3	41.2	34.5
6.2	6.92	-12%	10.2	4.8	53%	8.4	7.9	6%	7.6	7.27	4%	17	19.4	-14%	14.3	9.89	31%	9.3	7.12	23%	7.6	7.57	0%	5.8	4.24	27%	5.2	4.22	19%	5.3	5.09	4%	6.6	4.46	32%	8	2	52	50.67	51.5	38.21
5	3	40%	5	3	40%	13	4	69%	12	5	58%	12	9	25%	18	8	56%	5	4	20%	5	3	40%	4	3	25%	5	3	40%	5	3	40%	5	3	40%	9	2	44	26	50	25
5.6	2.9	48%	7.2	3.8	47%	6.1	5.3	13%	5.8	7.1	-22%	13	10.6	18%	17	20.1	-18%	4.3	3.2	26%	7	3.4	51%	3.7	3.3	11%	4.1	2.7	34%	4.5	3.3	27%	4.6	3.3	28%	9	2	37.2	28.6	45.7	40.4
6.2	4.3	31%	5.6	4.4	21%	6.9	7.6	-10%	7.5	6.9	8%	10	10.4	-4%	17	11.8	31%	7.6	5.1	33%	7.2	9.4	-31%	4.6	3.6	22%	4.6	3.5	24%	4.6	3.8	17%	5.3	3.9	26%	10	2	39.9	34.8	47.2	39.9
3	2	33%	3	3	0%	5	5	0%	6	5	17%	6	6	0%	11	9	18%	4	3	25%	7	2	71%	2	1	50%	2	2	0%	2	2	0%	2	2	0%	11	2	22	19	31	23

dom pre	dom post
5.26	4.55
7.35	7.05
12.82	11.64
6.93	6.27
4.5	3.81
4.66	3.94

dom pre	dom post	2012-2013 together
5.3	4.49	
7.95	7.32	
23.45	12.44	
7.74	7.53	
4.54	3.97	
4.98	3.92	





		TD pre	TD post	TND pre	ND post
6	1	85.5	70.1	110.3	72.1
6	1	43.08	45.94	48.25	51.26
6	1	52.1	75.6	69.9	62.4
7	1	86	42	150	65
7	1	53	36	49	37
7	1	75	33	56	44
7	1	41.28	36.6	47.8	38.5
8	1	41.98	33.2	56.46	43.3
8	1	42	32	45	33
8	1	46.4	42.29	56.31	49.78
8	1	52.2	54	62.58	63.6
8	1	49.51	27.53	60.11	36.51
8	1	48.7	31.2	44	37.7
9	1	40	30	107	25
9	1	44.6	51	53.2	41
9	1	36	29	49	30
9	1	59	42	66	64
9	1	152.5	118.5	128	129.5
9	1	41.68	36.94	46.79	50.9
9	1	44.2	38.4	46.1	37.9
9	1	48.97	40.98	54.82	42.83
9	1	32	34.4	37	34.3
10	1	40.2	33.63	34	38.52
10	1	28.3	37.2	33.2	40.4
10	1	53	34	45	30
10	1	31.7	30.3	40.1	28.3
10	1	36.86	29.4	36.2	31
10	1	48.9	38.5	63.3	47.3
11	1	33.01	33.67	36.36	36.3
11	1	25.5	23.3	27.8	25.7
12	1	347	92	76	35
12	1	33	32.7	135	94.2
12	1	35.6	40.1	44.1	39.7
12	1	38.42	31.05	50.31	37.83
12	1	43.4	27.5	39.1	31.3
17	1	23	16	25	18
6	2	51	34	56	41
6	2	40.7	32.3	41.2	34.5
8	2	52	50.67	51.5	38.21
9	2	44	26	50	25
9	2	37.2	28.6	45.7	40.4
10	2	39.9	34.8	47.2	39.9
11	2	22	19	31	23

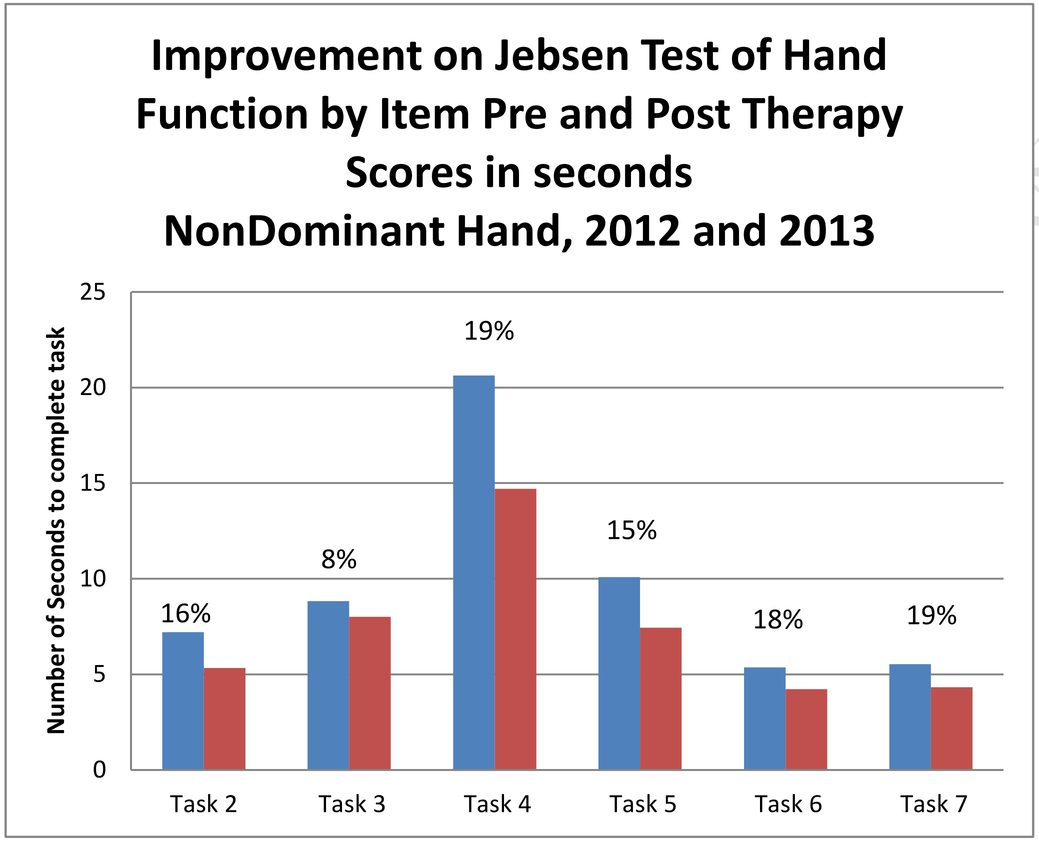
			6 and 7 Boy		n=7
	TD pre	TD post	TND pre	ND post	
data	62.28	48.46	75.89	52.89	
norm	40.9		43.2		
		8 and 9 Boys			n=15
data	51.98	42.76	60.82	47.95	
norm	35.7		40		
		10 and 11 Boys			
data	37.18	32.50	39.50	34.69	n=8
norm	33.5		31.5		
		12-14 Boys			
data	72.077	56.786	58.254	47.606	n=5
norm	27		29.9		
		15-19 Boys			
data	23	16	25	18	n=1
norm	26.5		28.4		
		6 and 7 Girls			n=2
data	45.85	33.15	48.6	37.75	
norm	42.5		47.5		
		8 and 9 Girls			n=3
data	44.40	35.09	49.07	34.54	
norm	32.1		25.6		
		10 and 11 Girls			n=s
data	30.95	26.9	39.1	31.45	
norm	29		31.9		

dominant			
Pre	post	Pre	Post
36	76	31	62

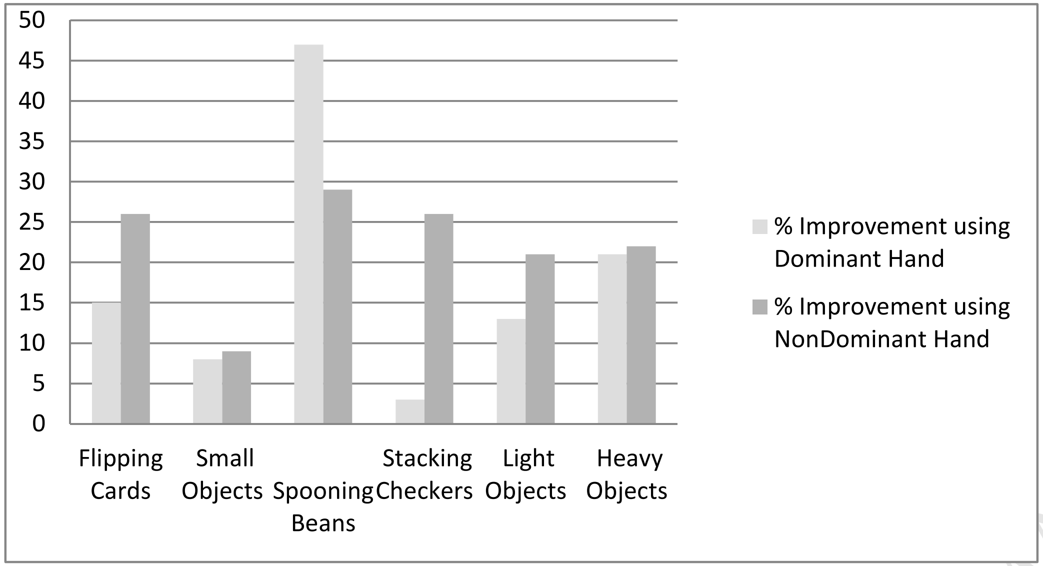
Figure 3.

Performance based on Total Scores on JTTHF pre and post therapy with regard

7.21	5.32
8.82	8
20.63	14.7
10.09	7.44
5.36	4.22
5.53	4.32



	dominant		
Pre	post	Pre	Post
36	76	31	62


50
45
40
35
30
25
20
15
10
5
0
Flipping Cards
Small Objects
Spooning Beans
Stacking Checkers
Light Objects
Heavy Objects
% Improvement using Dominant Hand
% Improvement using NonDominant Hand

subtest #	% uno DH	%imp NDH
2	15	26
3	8	9
4	47	29
5	3	26
6	13	21
7	21	22

Highlights

*Interactive Metronome training improved timing skills in 47 out of 48 children

*Both dominant hand and non-dominant hand function significantly improved

*Dominant and non-dominant hand function improved in different ways

*The patterns of hand function improvement are consistent with neuroscience research