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Improved Hand Function in Children with Cerebral Palsy with Repeat Doses of Group Based Hybrid Pediatric Constraint-Induced Movement Therapy

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Abstract: The study's aim is to analyze the improved hand function and bimanual performance with unilateral cerebral palsy (CP) from repeat doses of an augmented, group-based pediatric constraint-induced movement therapy (pCIMT) camp. Fifteen children with unilateral CP (ages 5–15 years, 9 male, 6 female, Manual Abilities Classification System (MACS) I = 3, MACS II = 11, and MACS III = 1) participated in two sessions of an annual pCIMT camp. Participants attended 10 days of camp where they received group-based training wearing a constraint for a total of 50 h, received bilateral, occupation-based activities for 10 h (60 h total) including 30 min each day on the Hocoma Armeo®Spring. The Assisting Hand Assessment (AHA) was administered pre-intervention and post-intervention. Our results discovered a mean interval dose 1 and 2 was 511 days. Dose 1 mean AHA score at baseline was 55.93 ± 12.78 and 63.07 ± 12.85 at post. Dose 2 mean AHA score as 58.13 ± 14.83 and post 66.53 ± 12.82. In conclusion, there was an overall significant bimanual functional improvement based on AHA scores that indicate, regardless of which camp session, scores improved from pre-intervention to post-intervention. There was a generalized upward trend in improved hand function of a group-based pCIMT, and diminished effects between doses were reversed with repeat doses.

Keywords: cerebral palsy; children; constraint-induced movement therapy; repeat doses

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1. Introduction

Cerebral palsy (CP) is the leading childhood motor disorder in the United States and affects 1 in 323 children [1,2]. CP is defined as a congenital, non-progressive motor disorder caused by a brain lesion that occurs in the early stages of development and persists throughout adulthood [3]. Children with CP present with postural instability, spasticity and musculoskeletal impairments that limit their motor development and daily activity performance [3]. Children with unilateral CP (UCP) have muscle weakness on one side of the body that leads to bilateral discoordination and motor impairments in the upper extremities (UE) [3]. As a result, children with UCP often compensate for their affected limb by only using their unaffected limb to complete daily tasks. In time, the lack of use of their affected limb develops into the phenomenon of "learned non-use". Learned non-use is the motor deficit that is caused by the repeated failures of the affected limb in task performance and leads to a voluntary, preferential movement of the functional limb [4]. As a result, learned non-use requires cortical reorganization and behavioral reinforcement to counter-condition the reliance of the preferred limb and establish improved motor function of the non-preferred limb [4,5].

In order to overcome learned non-use, constraint-induced movement therapy (CIMT) is a widely-recognized, effective therapy intervention used for adults with stroke and children with UCP to improve bilateral coordination of the UE [4,6–8]. CIMT restrains the preferred or unaffected limb to promote the functional independence of the non-preferred limb and overall bimanual performance in the UE [4]. CIMT reverses the effects of learned non-use through repetitive tasks that promote cortical reorganization by shaping motor skill development [4]. Upon the emergence of CIMT, pediatric constraint-induced movement therapy (pCIMT) was developed to analyze the specific benefits of CIMT in pediatrics. For more than 15 years, pCIMT has been a beneficial intervention for children with diagnoses that include, but are not limited to: CP, brain tumors [9], acquired brain injury [10], and Erb–Klumpke palsy [11].

CIMT is an effective intervention for children UCP as it promotes UE activity and participation of the non-preferred limb when compared to no intervention and has real-life applications [8,12]. In a systematic review of 36 randomized control trials (RCT) by Hoare et al. [13], CIMT administered with goal-directed, well-defined and time-limited blocks was found to be more effective in greater doses when compared to low-dose administration. The dosage of CIMT and its effects play an important role in the functional improvement of the non-preferred limb for children with UCP. A priority for future research is to further reexamine the long-term effects associated with overall dose and with repeat doses of CIMT on motor development for children with CP. Although CIMT is effective, there is a primary gap in the literature that suggests the need for repeat doses of CIMT of the same design among 1-year intervals in order to explore the dose–response relationship and identify the age in which a ceiling effect occurs [14,15].

A literature review conducted by expert panelists in CIMT recommended that additional areas for future research should investigate the role of the environment including the effect of group-based training programs, and investigate the impact of innovative training methods, such as computer games and virtual reality [15]. In 2021, Roberts et al. [16] published the results of a pilot study of an augmented pCIMT camp aimed to fill these gaps. The implementation of the group-based, augmented pCIMT demonstrated statistically and clinically significant positive effects on the independence in occupational performance and improved bimanual hand skills [16]. However, further analysis of the long-term effects caused by repeat doses of the augmented pCIMT camp in children with UCP is needed.

In addition, the literature supports the use of group therapy in the delivery of CIMT as it allows the participants to support and collaborate with one another and overcome their frustrations and difficulties more effectively by providing "healthy competition" that increases motivation [17,18]. However, there are no studies that report on the impact regarding the novel approach of repeat doses of an augmented, group-based pCIMT protocol in children with UCP. Our research protocol is in alignment with previous studies [13,18] that discuss the recommendation that children with CP should receive group-based training to promote engagement and motivation beneficial to improve their motor abilities. Children with UCP participating in group-based CIMT make significant gains as it increases the use of the affected UE during self-care activities and play through friendly competition and camaraderie between participants [13]. Due to benefits associated with group-based therapy in children with CP, our study focuses on children with UCP to participate in unilateral and bilateral activities in a group-based pCIMT camp setting combined with a virtual reality component.

Analysis of the pilot study data aims to address the impact of repeat doses of an augmented pCIMT protocol delivered in a peer-supported group environment on bimanual skills in children with UCP. The hypothesis for the study is that repeated doses of the augmented pCIMT camp will result in greater improvements in hand function compared to a single dose of the intervention.

2. Materials and Methods

2.1. Participants and Setting

This study is a prospective case series in succession to the Roberts et al. [16] study to investigate the dosage-effect relationship to promote improved hand function using a pCIMT camp-based protocol for children with UCP. A convenience sample of 15 children with UCP aged 5 to 15 years-old (9 male, 6 female, MACS I = 3, MACS II = 11, and MACS III = 1) that attended two pCIMT camp sessions at a pediatric orthopedic hospital in south-eastern United States between the summers of 2014–2019. All subjects attended the camp sessions consecutively, with the exception of one child who returned the following year.

The Manual Ability Classification System (MACS) is an objective measure used to classify the subtypes of CP based on the bimanual ability of children with CP when participating in daily activities [19]. MACS has five classification levels with the lowest level being the most functional handling objects independently and the highest level demonstrating the most limitations in the UE [19]. For the purpose of this study, MACS was used to classify upper limb dysfunction in participants that are between MACS I and III with a fairly equal distribution with slightly more children at MACS II.

Children were excluded from the study based on the following criteria: (a) significant visual impairments or (b) history of seizures. Participants provided informed assent and their legal guardians voluntarily granted written informed consent to study investigators prior to camp enrollment. In addition, voluntary participation in the study did not disrupt their standard of care, and the data obtained from the study were de-identified to use for educational and research purposes. The research was approved by the Institutional Review Board at the University of Texas Southwestern Medical Center and all affiliated institutions to conduct the annual pCIMT camp to correspond to the STU 042014-013.

2.2. Outcome Measures

The Assisting Hand Assessment (AHA) is a performance-based assessment that measures how effective children with upper limb impairments uses their non-preferred UE as an assisting hand (AH) during bimanual activities in a fun and playful environment. The AHA assess the child's usual performance of bimanual skills, not their capacity [20]. For the purpose of the study, the AHA is a primary outcome measure intended to create a baseline to detect hand function changes from pre-intervention to post-intervention. Based on the administration manual, the AHA assesses 22 items using a four-point rating scale that scores the use of the affected limb, grasp and release, fine motor movements, range of motion, coordination and accuracy [20,21]. Additionally, AHA has a strong inter- and intra-rater reliability and construct validity to measure bimanual performance in children with upper limb impairments [21,22]. For the purpose of the study, AHA was scored by certified raters that were not the study investigators in order to reduce researcher bias and the scores were de-identified for data analysis.

2.3. Intervention

For the analysis of repeat doses of pCIMT, the camp protocol followed the Roberts et al. [16] study using a training manual and utilized a 1:1 interventionist ration with trained interventionists. Trained interventionists were occupational therapy students seeking to receive fieldwork credits or college students enrolled in an allied health program. Trained interventionists received instructional education and hands-on learning from the study investigators that covered an overview of unilateral CP pCIMT, upper-limb assessments and the research study protocol including the camp schedule and training on shaping motor activities in order to maintain treatment fidelity and ensure participant confidentiality.

Each participant attended the annual pCIMT camp for two weeks and had six hours of therapy each day (60 h total) during the summers of 2014–2019 [16]. The augmented pCIMT camp protocol was an adaptation of Boyd et al. [23] INCITE camp. During the augmented pCIMT camp where the participant's preferred UE was constrained using a long arm gutter splint for five and a half hours including the use of the Hocoma Armeo®Spring for 30 min

daily [16]. The remaining 30 min of each day and the last day of camp focused on bimanual hand skills for a total of 50 h of pCIMT and ten hours of bimanual practice over two weeks. After each session, the restraint was removed to allow participants to practice bimanual activities within their natural environment.

2.4. Data Analysis

Research records were reviewed to identify children who completed two pCIMT camp sessions and to extract demographic information. Next, scores for AHA were analyzed using a factorial repeated measures ANOVA with a within-subjects factor to determine if differences existed between pre and post camp for the 15 participants and whether these differences were influenced by whether the participant was in their 1st or 2nd camp.

3. Results

3.1. Subject Characteristics

Table 1 presents demographic data for the 15 children who received at least two doses of pCIMT. The mean interval between doses was 511 days. All had a primary diagnosis of unilateral cerebral palsy with 53% left hemiparesis. Most children were classified as a MACS II; levels ranged from MACS I–III. Of these, 60% were boys.

Table 1. Participant Characteristics (n = 15).

Characteristic	Received Two Doses of pCIMT (n = 15)
Mean age, months	
Dose 1	91
Dose 2	108
Age range, months	63–180
Gender, n (%)	
Boys	9 (60)
Girls	6 (40)
Side of hemiparesis, n (%)	
Right	7 (46)
Left	8 (53)
MACS level, n (%)	
I (least impaired)	3 (20)
II	11 (73)
III	1 (6)

Note. MACS = Manual Ability Classification System; pCIMT = pediatric constraint induced movement therapy; SD = standard deviation.

3.2. Hand Function Changes

As presented in Figure 1 and Table 2, there was an increase in the AHA score means from pre-intervention to post-intervention for dose 1 and 2. Dose 1 had a mean AHA score at initial baseline at 55.93 ± 12.78 and post-intervention at 63.07 ± 12.85. Dose 2 had a mean pre-intervention AHA score of 58.13 ± 14.83 and post-intervention score of 66.53 ± 12.82. Before main effects for time and dose were examined, the interaction effect between time and dose was considered. The results showed no significant interaction effect ($F(1,\ 14) = 0.99,\ p = 0.336,\ partial\ \eta^2 = 0.07$), so main effects could be interpreted normally. Results from the analysis revealed that significant differences existed between pre and post camp AHA scores ($F(1,\ 14) = 49.89,\ p < 0.001,\ partial\ \eta^2 = 0.78$). Based on the data, there was a clinically and statistically significant increase in AHA means in treatment 1 and the same trend carryover in dose 2 in children with UCP enrolled in pCIMT camp.

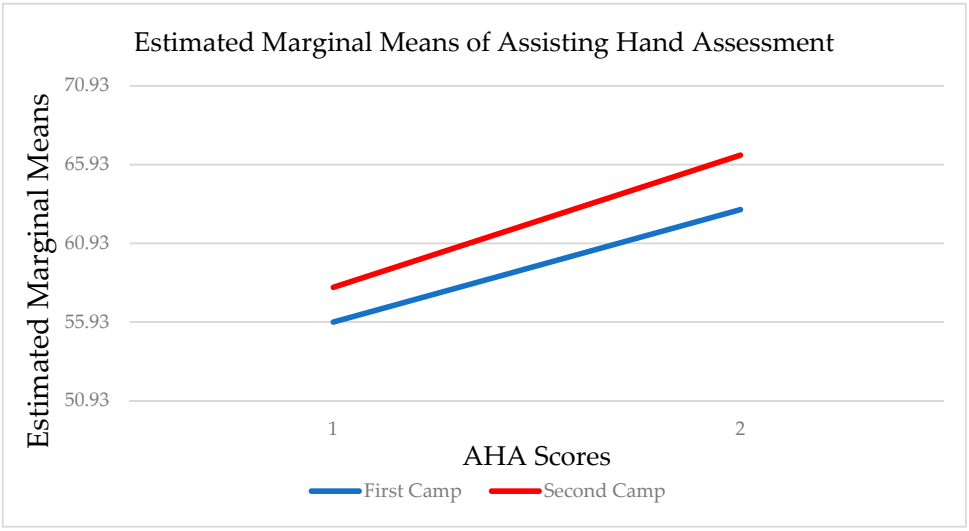

Figure 1. Marginal means of the Assisting Hand Assessment (AHA).

Table 2. Descriptive statistics of marginal means of the Assisting Hand Assessment (AHA).

	Camp Frequency	Mean	Standard Deviation
Pre-AHA	First Camp	55.93	12.781
	Second Camp	58.13	14.832
	Total	57.03	13.801
Post-AHA	First Camp	63.07	12.853
	Second Camp	66.53	12.822
	Total	64.80	12.837

3.3. Carryover Effect between Repeat Doses

As depicted in Figure 2, there was a decrease in hand function occurred between dose 1 and 2 as the initial baseline AHA score for dose 2 was 58.13 ± 14.83 decreased from post-intervention for dose 1 with a mean AHA score of 63.07 ± 12.85. This constitutes a statistically significant decrease from the end of dose 1 to the beginning of dose 2 ($t(14) = 2.36$, $p = 0.034$, *Hedges'g* = 0.58), indicating a "wear-off" effect. However, the participants presented with a higher baseline in hand function in dose 2 (mean 58.13 ± 14.83) than dose 1 (mean 55.93 ± 12.78) that can be attributed to a carryover effect as participants sustained some bimanual performance from the previous camp session. The difference for baseline scores between doses 1 and 2 was insignificant ($t(14) = -1.61$, $p = 0.130$, *Hedges'g* = −0.39), so this should not be too concerning. In addition, the effects of diminished hand function between dose 1 post-intervention to dose 2 baseline were reversed as participants maintained an increase in bimanual hand function with an average increase of 8 AHA logits in both camp sessions. No significant difference was shown to exist between the 1st and 2nd camp attended ($F(1, 14) = 3.81$, $p < 0.071$, *partial* $\eta^2 = 0.21$). However, the effect size for the 1st and 2nd camp AHA score differences could have been considered meaningful, with over 21% of the AHA score variance being explained by whether it was the participants' first or second camp. An examination of the standardized mean difference between the first and second camp also shows a small-to-moderate effect (*Hedges'g* = 0.48). This effect is larger than that found by Gordon et al. [24] (*Hedges'g* = 0.34) and suggests that a larger sample could show that differences exist between the first and second camp attended for AHA outcomes.

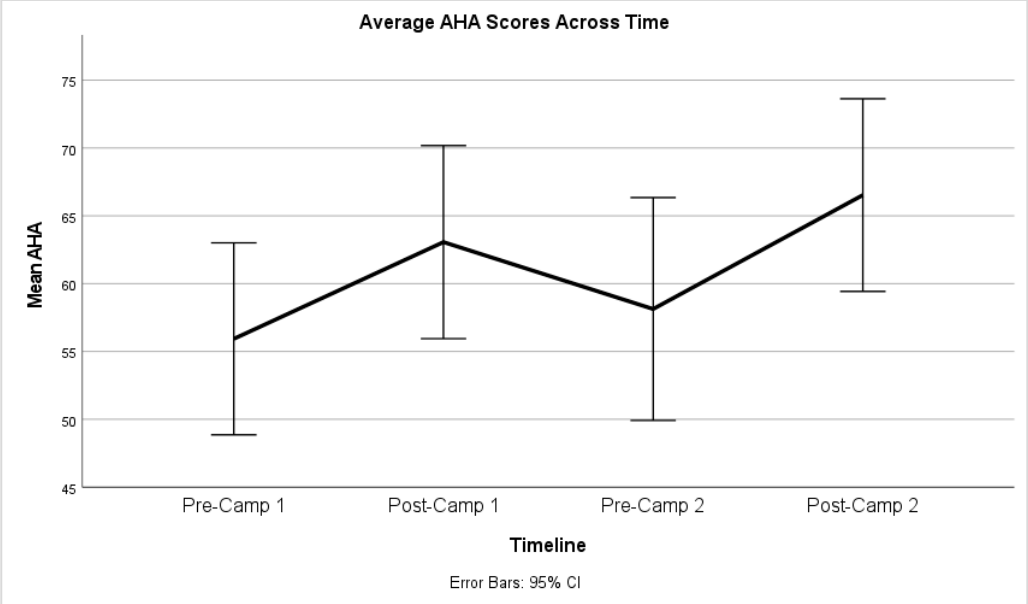

Figure 2. Average AHA scores with 95% CI.

4. Discussion

This analysis, Figures 3–17, shows improved bimanual performance in children with UCP receiving repeat doses of an augmented, group-based pCIMT camp. Based on the study findings, there was decreased bimanual performance between doses as AHA mean scores declined from post-intervention in dose 1 to the pre-intervention in dose 2. However, the baseline AHA scores at the beginning of dose 2 were higher than the baseline AHA scores for dose 1 which demonstrates a carryover effect occurred in children with UCP participating in pCIMT camp. At the beginning of dose 2, participants had initial gains in AHA scores that then led to an even higher post-intervention AHA score at the end of dose 2 as compared to dose 1. As a result, the second dose of pCIMT camp reversed the diminished effect observed between the doses which confirms a need for repeat doses of pCIMT in children with UCP to maximize long term effects in bimanual hand function. The outcomes of the DeLuca et al. [14] study follow the same trend of decreases between doses followed by higher hand function gains post-treatment. Overall, the results of the study indicated that there was significant bimanual functional improvement as it was determined by the AHA that, regardless of which camp session, scores improved from pre-intervention to post-intervention. More research is needed to fully investigate the dose–response relationship effect in order to determine when a ceiling effect occurs.

Based on a literature review conducted by Eliasson et al. [15], it was recommended that future studies should investigate the effects of CIMT with repeat doses of the same design in 1-year increments to establish the threshold in which a ceiling effect occurs. To our knowledge there are limited studies that monitor the UE gains associated with multiple doses of CIMT among children with CP [14,15]. DeLuca et al. [14] found overall statistically and clinically significant gains in UE skills above initial baseline from multiple doses of CIMT in children with CP. In our study, the same trend occurred with statistically and clinically significant increases in hand function and bimanual performance from pre-intervention to post-intervention with repeat doses of our pCIMT camp. The study findings may support the recommendation of a smaller time interval between doses, which may need to be smaller than 1–2 years in order to limit the diminished hand function between doses. The continued investigation of the improved effects in hand function and bimanual performance in children with UCP receiving repeat doses of CIMT can further identify the optimal dose–response relationship. In regards to the dose–response relationship, we had similarities with previous studies as children with CP between CIMT doses expected declined in the acquired skills and daily use of their affected UE, but

this was remedied through repeat doses of pCIMT [14,15]. DeLuca et al. [14] analyzed the effects of repeat doses of pCIMT in children with CP receiving six hours daily of therapy for five days per week for four weeks (total 20–21 days) for 2–3 doses and found significant improved hand function and bimanual performance. Based on a systematic review by Hoare et al. [13] of 36 randomized control trials, it was indicated that the correct dosage in CIMT administration is dependent on many factors (e.g., duration of therapy, type of constraint, therapist or parent) and cannot be adequately determined without the confirmation of replicated interventions. With our analysis, we discovered a "wear-off" effect between doses that was reversed with repeated doses of pCIMT camp in children with CP. The applicable nature of repeat doses based on the DeLuca et al. [14] study confirms repeat doses of pCIMT can produce long-term effects in bimanual hand ability. In an effort to eliminate any contraindications, the dosage of our pCIMT camp was consistent and followed the camp manual in order to confirm the validity of our study through replicated trials. Through the consistency of our pCIMT camp across doses, we properly concluded that the continued effects of increased hand function and bimanual performance persisted in children with CP with repeat doses of pCIMT, and this will continue to be investigated by ongoing analysis in our prospective series.

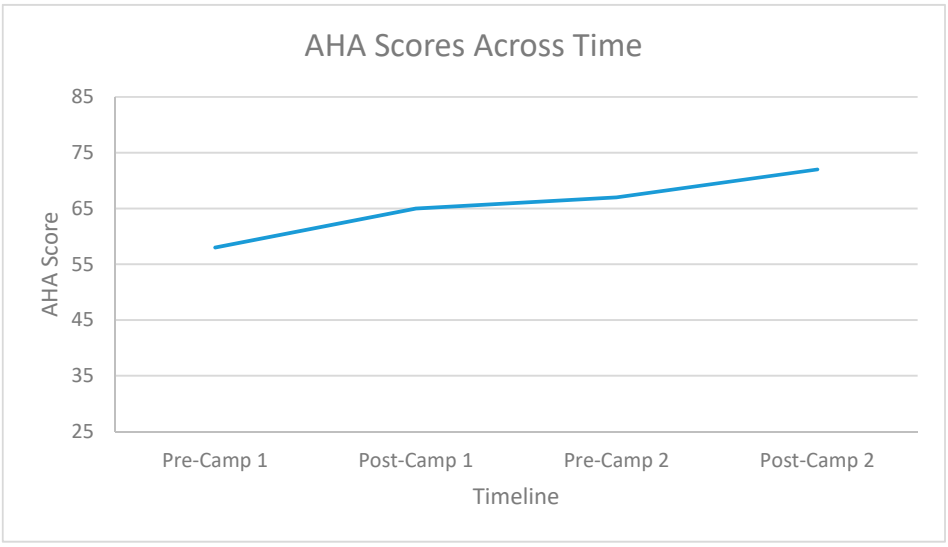

Figure 3. Subject 1 AHA score across time.

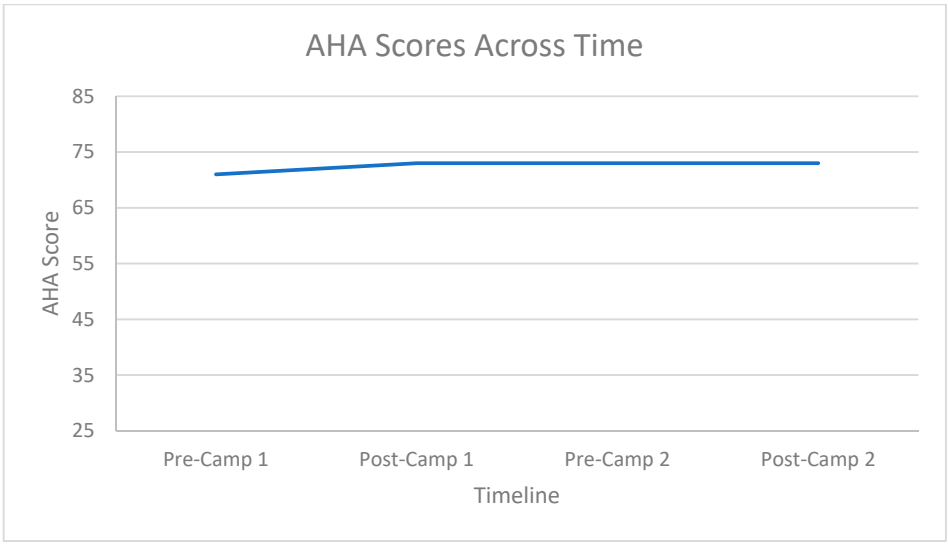

Figure 4. Subject 2 AHA score across time.

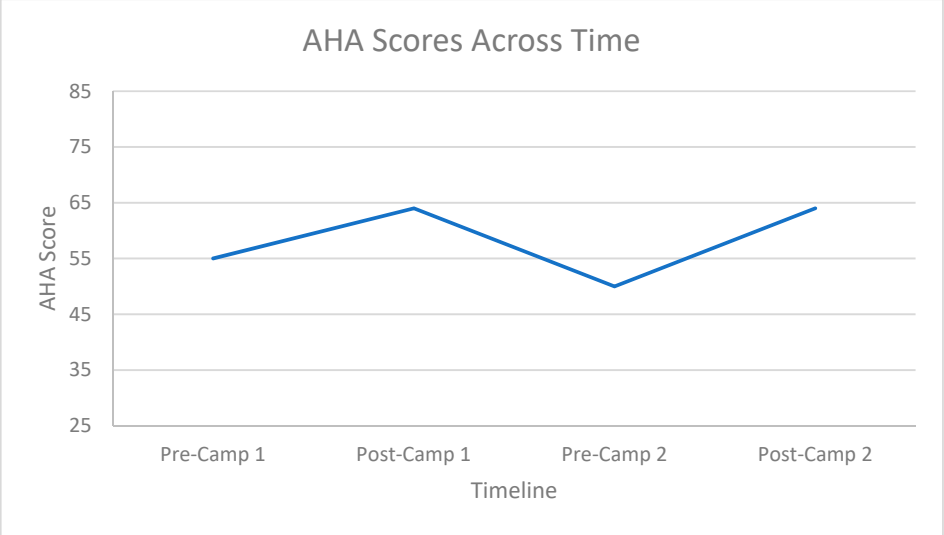

Figure 5. Subject 3 AHA score across time.

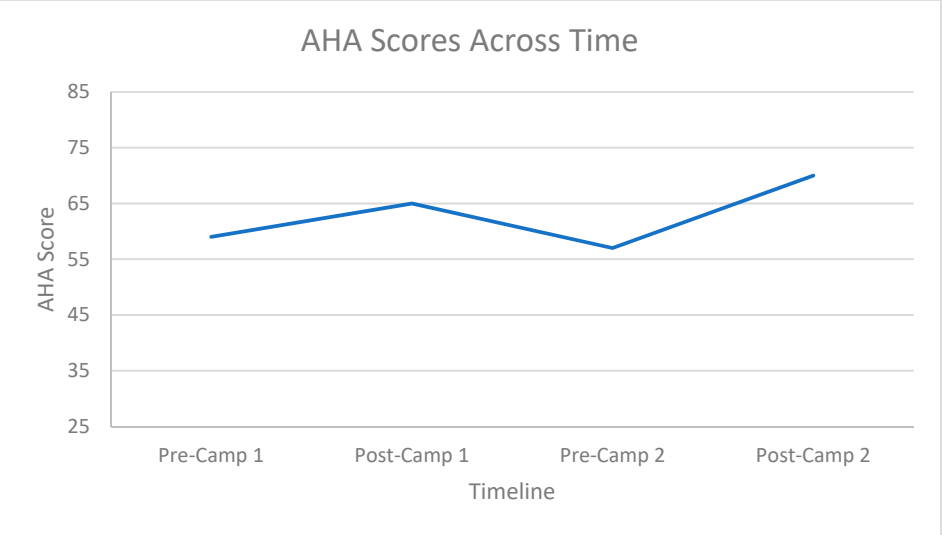

Figure 6. Subject 4 AHA score across time.

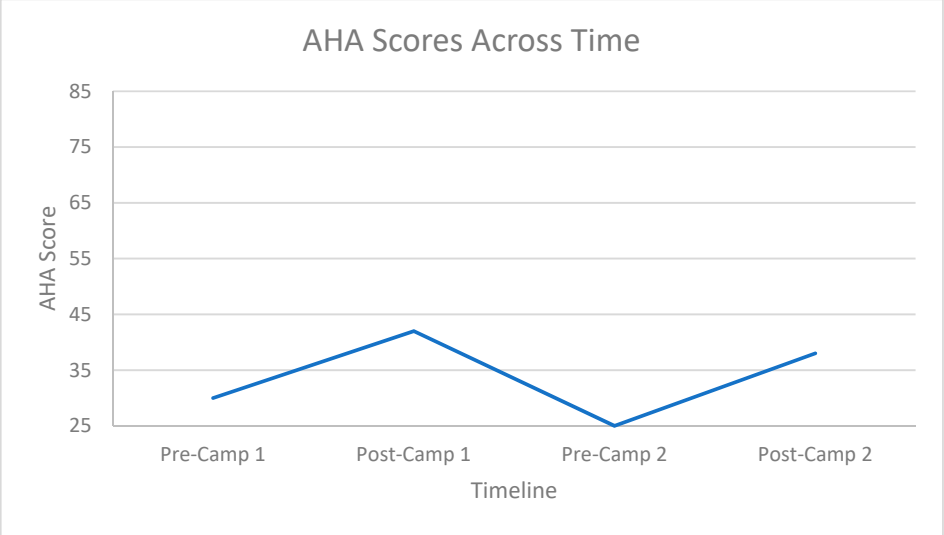

Figure 7. Subject 5 AHA score across time.

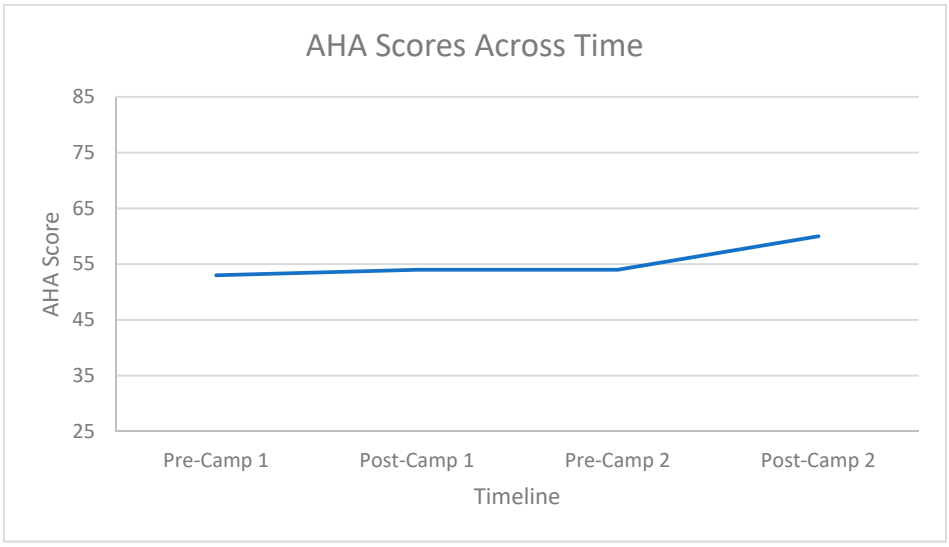

Figure 8. Subject 6 AHA score across time.

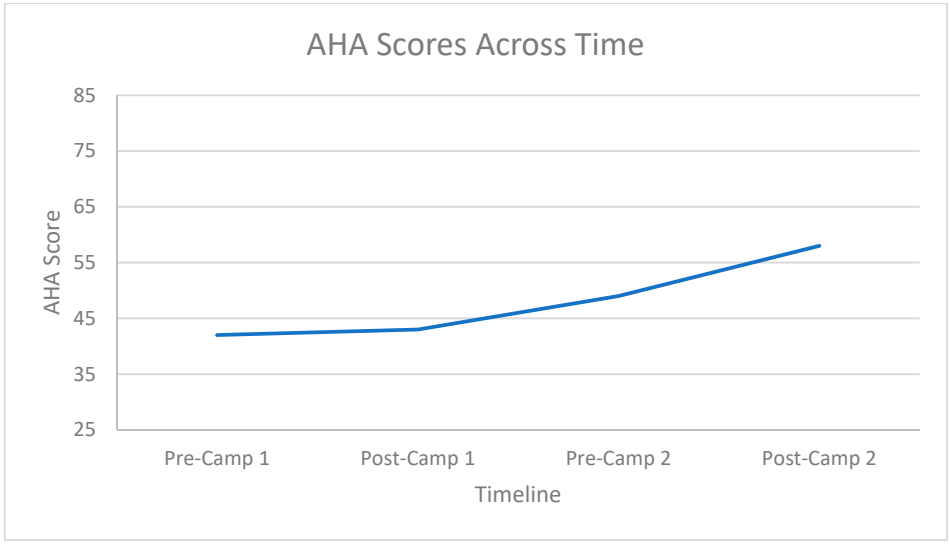

Figure 9. Subject 7 AHA score across time.

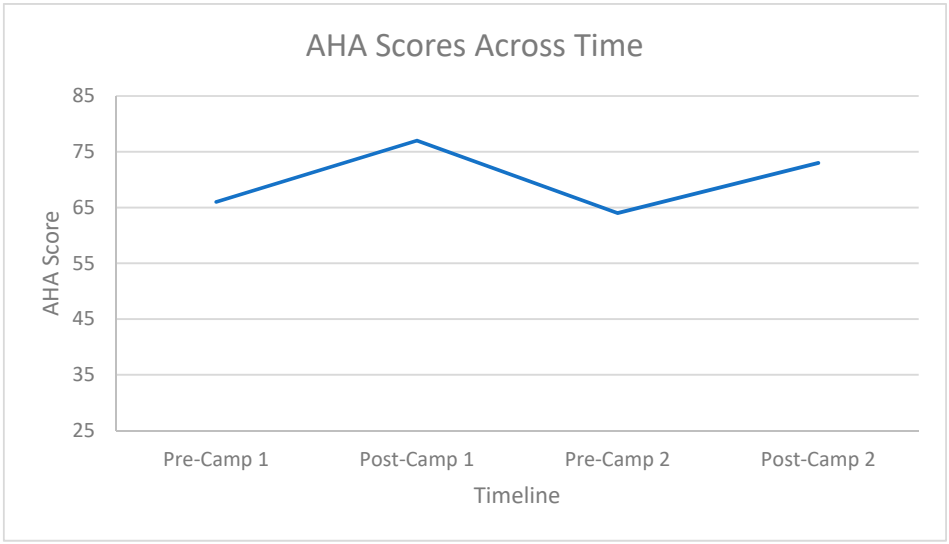

Figure 10. Subject 8 AHA score across time.

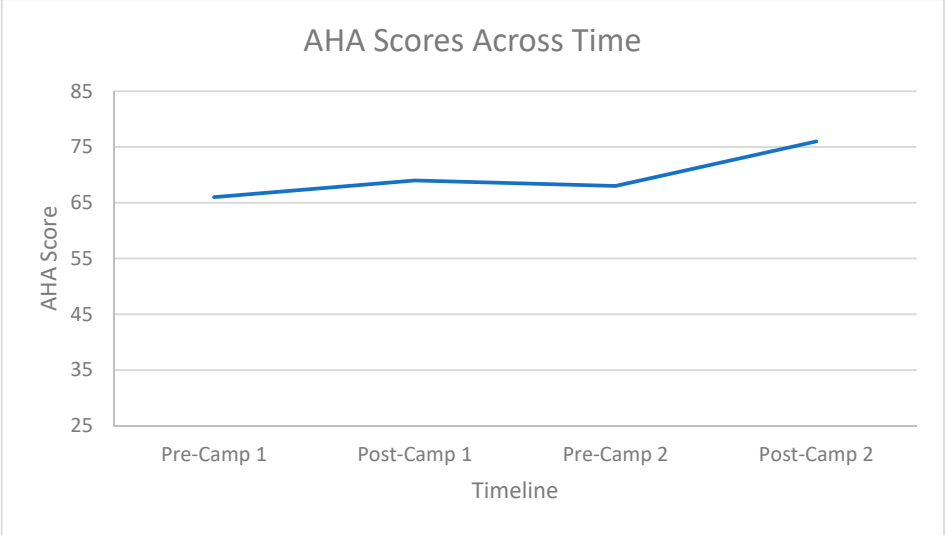

Figure 11. Subject 9 AHA score across time.

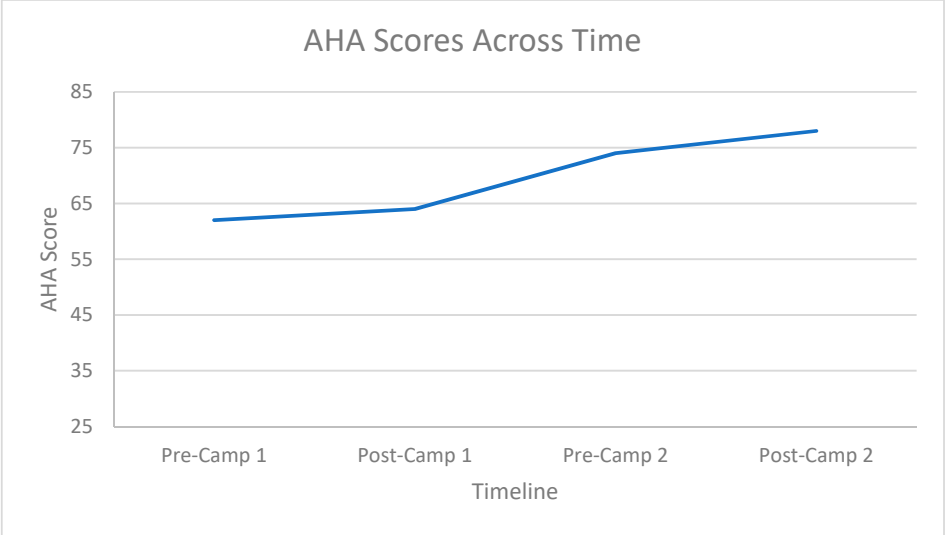

Figure 12. Subject 10 AHA score across time.

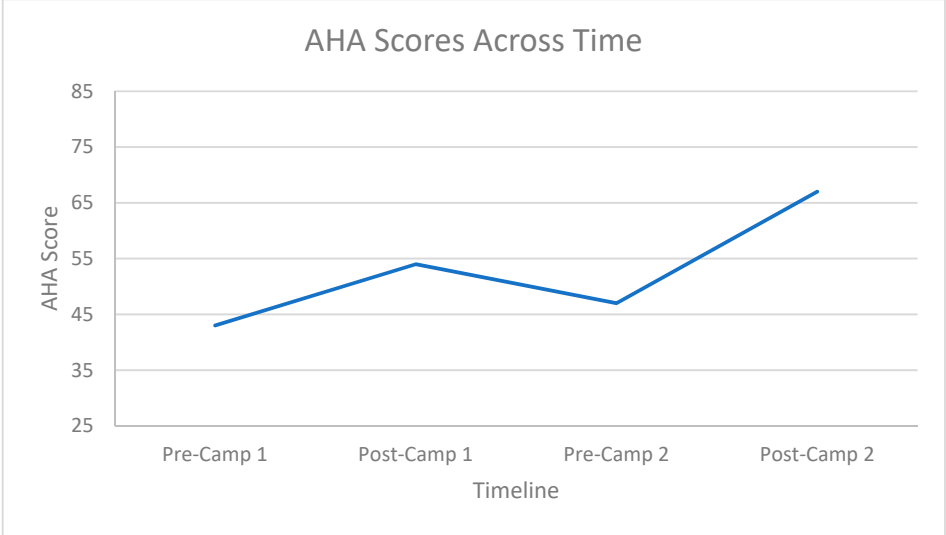

Figure 13. Subject 11 AHA score across time.

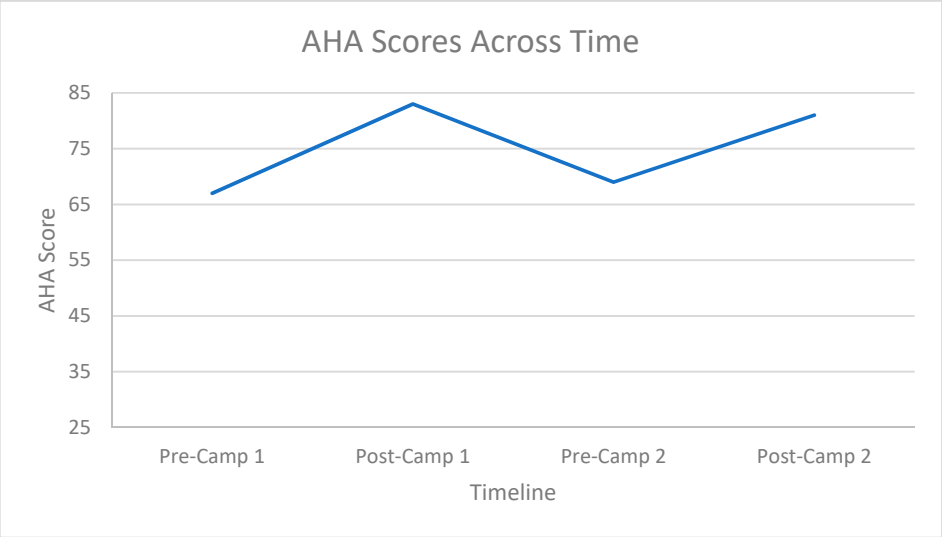

Figure 14. Subject 12 AHA score across time.

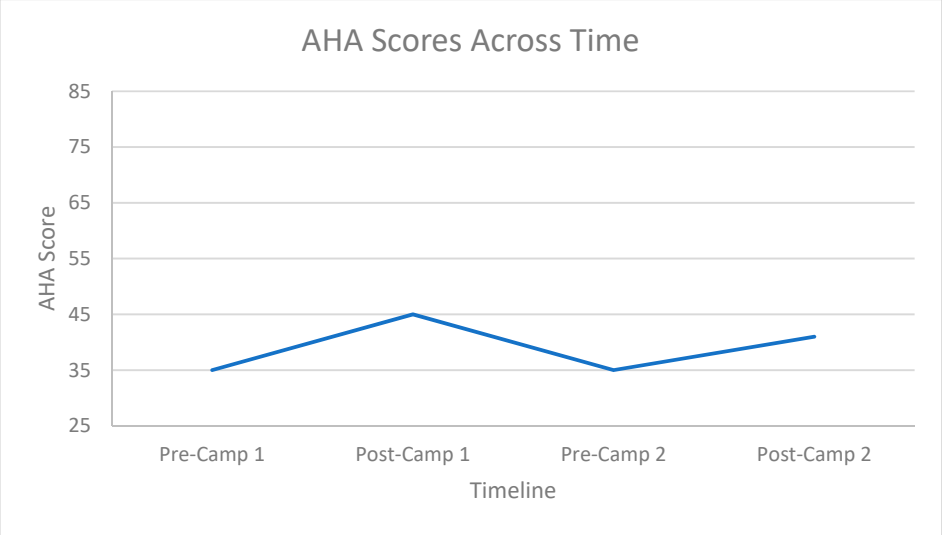

Figure 15. Subject 13 AHA score across time.

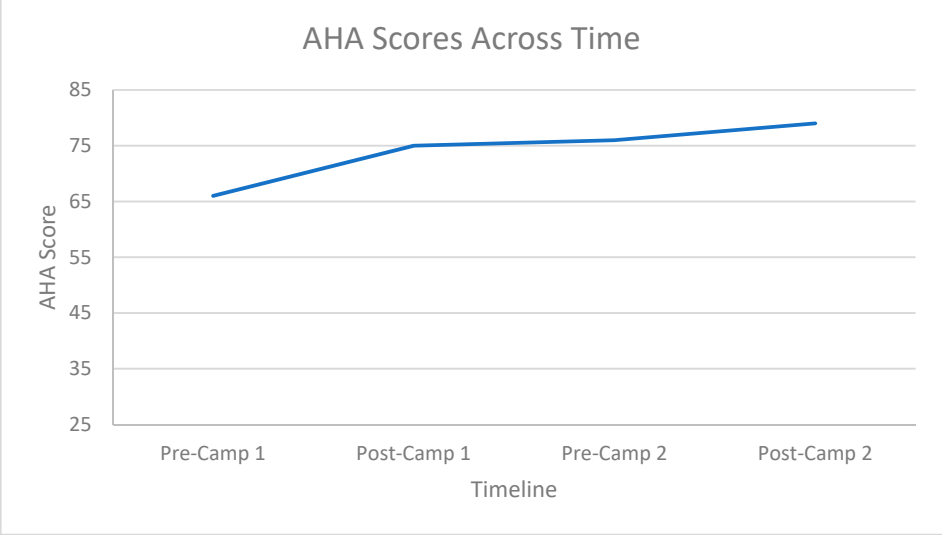

Figure 16. Subject 14 AHA score across time.

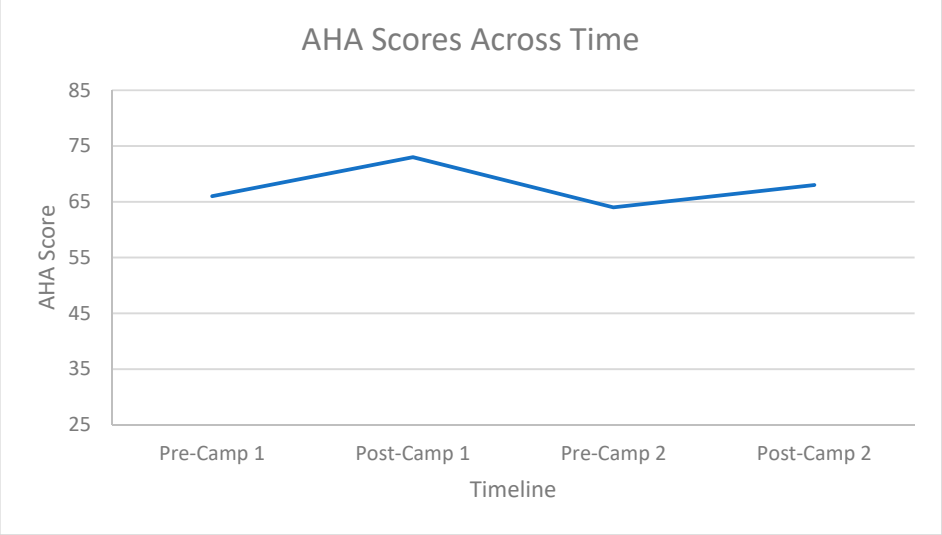

Figure 17. Subject 15 AHA score across time.

4.1. Limitations

A limitation within this study was that participants had slightly invested parents that were proactive and invested in their child's treatment which may have influenced their child's improved hand function during the program. In addition, participants were recruited via convenience sampling limited within Texas which could have geographical limitations within our sample. Due to the limited geographical breadth and small sample size, the results from the study may have reduced generalizability to children with CP within the United States. It is critical to indicate that the findings are not representative of (a) children with CP subtypes aside from UCP, (b) children with developmental delays or disabilities and (c) children with comorbidities tandem to UCP. Research that includes a continued analysis of the repeat doses of pCIMT and longitudinal study of the long-term effects from pCIMT in children with UCP would be a valuable contribution to guide evidence-based practice.

4.2. Implications for Practice

Children with UCP made meaningful and significant gains in bimanual performance across two sessions of an annual augmented pCIMT camp with a virtual reality component. pCIMT intervention administered in a group-based camp setting can be beneficial to children with UCP as it promotes camaraderie, motivation, and friendly competition to occur between participants. In addition, it is recommended to lessen the amount of time between doses in order to promote the longevity of the long-term effects acquired from a group-based, augmented pCIMT camp.

5. Conclusions

This study demonstrates the improved hand function and bimanual performance from repeat doses of an augmented pCIMT camp in children with UCP. This research explores the dose–response relationship in the pCIMT protocol in order to guide clinical practice and maximize long-term effects in bimanual hand function in children with UCP. As children with UCP received repeat doses of pCIMT camp, future research is needed to explore the optimal dose–response relationship effect to mitigate the decline in hand function between doses. Overall, the study confirmed that repeat doses of pCIMT camp counter-conditioned the declined hand function between doses and maximized bimanual performance post-intervention in children with UCP.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available.

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