Effects of a Head Support on Children with Hypotonia in the Cervical Spine

Bradford Kerst[1,3], *Student Member, IEEE*, Lynda Crouch[2], Jamey Fox[2], Julie Wilson[2], and Joshua Schultz[1], *Senior Member, IEEE*

***Abstract*— Children with hypotonia of the muscles near the cervical spine have reduced head control and are unable to maintain an upright head posture. These children often use an external head support to hold their heads upright. With their head held in the proper position, they often develop more functional head movements. Previous studies have measured functional changes to subjects using the head support but have not studied the forces exerted on the head support. This study observes subjects with GMFCS Level V and their functional skills alongside the forces exerted on the head support over a 4-month period. A force sensor attached to the base of the head support was used to collect force data to compare with classroom observations of the child's functional performance by occupational and physical therapists. Subjects showed an increase of up to 67% in quadrants where they previously had ¡1% activity at the beginning of the study. Each subject had increased time exerting forces greater than the weight of the head in later weeks of data recording as well as increased peak forces magnitude. Studying the functional impacts of subjects using a head support with measured forces can highlight important aspects of skill development and progress towards milestones for children with hypotonia.**

***Clinical Relevance*— While using a head support, children with GMFCS Level V are able to maximize their head movement which helps them develop functional skills.**

I. Introduction and Background

The ability to hold one's head in an upright position is important for life-sustaining bodily functions, including breathing, feeding, and vision [1]–[5]. Hypotonia is a neurological symptom of many common movement impairing disorders, such as cerebral palsy, autism spectrum disorder, and down syndrome, that causes people to have reduced muscle tone [6]–[8]. Subjects in this study have severe cases of hypotonia near the cervical spine and have reduced head control as a result. The research was performed to understand if subjects with hypotonia near the cervical spine develop muscle strength and control while using a head suspension device based on numerical data from a 3-axis force sensor. Understanding how the head support helps subjects improve head control can lead to more efficient rehabilitation for subjects with hypotonia and movement impairing disorders [4]. A head suspension device may improve the muscle strength and head control for subjects with hypotonia in the cervical spine.

*This work was supported by the NSF (CBET-1706428).

[1] Department of Mechanical Engineering, University of Tulsa, Tulsa, OK 74104, USA. [btk291,joshua-schultz]@utulsa.edu

[2] Little Light House, Tulsa, OK 74135, USA. [lcrouch, jfox, jwilson]@littlelighthouse.org

[3] Corresponding author.

Previous research regarding the benefits of a head support is limited to clinical assessments. Clinical assessments and observations show benefits to children using a head suspension device, but data of the force exerted on the head support were not available prior to this research [9]. One study examined the difference in feeding subjects with and without the head support and found feeding with the head support was the same or better for each subject and caretaker [1]. Similar research used video recording to find active time and number of head bobs and found that active time holding their head upright increases and the number of head bobs decreases as a result of head support usage [10]. Studying the forces subjects exert on the head support can help understand the benefits from a mechanical perspective. The purpose of this study is to establish a baseline for how the forces exerted on the head support change over a 4-month period in combination with observations by physical and occupational therapists to better understand how providing head support promotes the ability to maintain a neutral head posture.

II. Subjects and Methods

A. Subjects

The research followed IRB protocol with the University of Tulsa's requirements for human subject testing. Four subjects were identified to have hypotonia based on clinical assessments and observations by occupational/physical therapists, including an Assistive Technology Professional and Certified Low Vision Therapist. Subjects were excluded from research that exhibited poor school attendance, did not tolerate the head support, and those who had the ability to maintain an erect neutral head posture for extended times. Subjects ranged from 4 to 5 years old when data collection started. Three subjects were male, one was female. One typically developing female was included for preliminary observations, e.g. head drops, flexion, extension, rotation, and lateral motions. The subjects demonstrated impaired movement disorders, which included hypotonia in the cervical spine, leading to reduced head control. Subjects were photographed in their individualized postural seating chairs with and without the head support to show their nominal head position. This research was conducted in an educational setting where functional skills are measured, where the Gross Motor Function Classification System (GMFCS) is more appropriate than manual muscle tests [11].

Each of the four subjects have diagnoses of GMFCS Level V (the lowest-functioning level on the scale) from hypotonia and cortical vision impairment (CVI) [12]. Subject

4 had fluctuating muscle tone, moving between hypotonia and hypertonia involuntarily. Additional clinical information related to head control for the subjects include:

Subject 1: Hypotonia; CVI; Seizures.

Subject 2: Hypotonia; CVI; Seizure disorder; fluctuating muscle tone with either significant extension or flexion; Retinopathy of prematuraty; Grade 4 intraventricular hemorrhage with perventricular leukomalacia.

Subject 3: Hypotonia; CVI; neurodevelopmental delay; intrauterine growth restrictions; deafness; nystagmus; optic nerve hypoplasia, high myopia; high astigmatism, severely impaired hearing with bilateral cochlear implants.

Subject 4: Mixed tone; CVI; Seizures; lissencephaly; Miller Dieker syndrome; infantile spasms; bilateral optic nerve hypoplasia; high hyperopia; Poor motor control and coordination of movement.

B. Data Acquisition

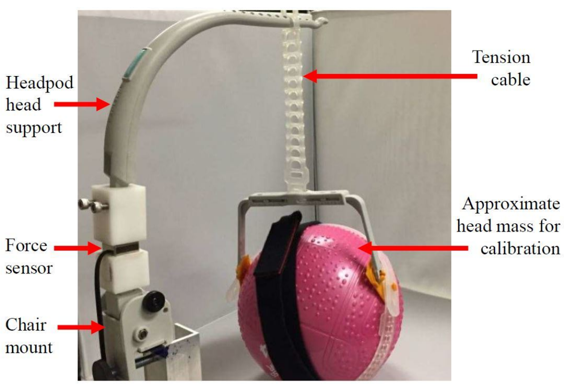

Fig. 1. Setup for data acquisition with Headpod head support and Tec Gihan triaxial force sensor.

A Siesta Systems Headpod head support was used for the head suspension device. The Headpod included an adjustable suspension arm that mounts to the back of an adaptable chair and holds the child's head via a tension cable [9]. An attachment was adapted to use the Headpod with a Tec Gihan 200 N 3-axis force sensor with a signal conditioner to gather data of the force exerted on the head support. This setup can be seen in Figure 1. The data was saved to a micro SD card via a Tiva TM4C123GXL microcontroller utilizing a voltage divider. Data was recorded by custom ANSI C software sampling at 36 Hz.

Teachers in the classroom were trained on proper use of the head suspension device from the Siesta Systems guidelines and operation of the data recording device. The teachers made notes of classroom activities, behavior, visual searching, and where the subject was seated with respect to the activity in the classroom on the days of recording that were later compared with the collected data. Teachers received training on both Headpod setup with the force sensor extension and optimal postural positioning (with attention to pelvic and trunk alignment, as this affects head position).

Data was collected over a 4-month period with a 3-week break after Week 5, and a 3-week break after Week 14. Subject 1 left after Week 16. Data collection is ongoing, and future data sets may illuminate a future work.

C. Data Analysis

The force data was filtered using a five-point moving average low-pass filter in Wolfram Mathematica to create a data sheet including the time spent in various force ranges based on the weight of the head. The estimated weight of the head was 20 N (4.5 lbs) as a reference value for each of the subjects [13]. The force range values were chosen to indicate when the Headpod provided support and when it provided resistance to maintain a more neutral head posture. The Wolfram Mathematica code extracts the total time, maximum force, number of times the force exerted on the head support crossed a 80 N threshold, and time stamps when the threshold was crossed. Time stamps were used for further inspection of stronger pulls on the head support from the data and exports it to a readable data sheet. Classroom teachers recorded the seat placement relative to the teacher, activities the class did on data recording days, and engagement and behavior of the participants during each session to compare with data sheets.

III. Results

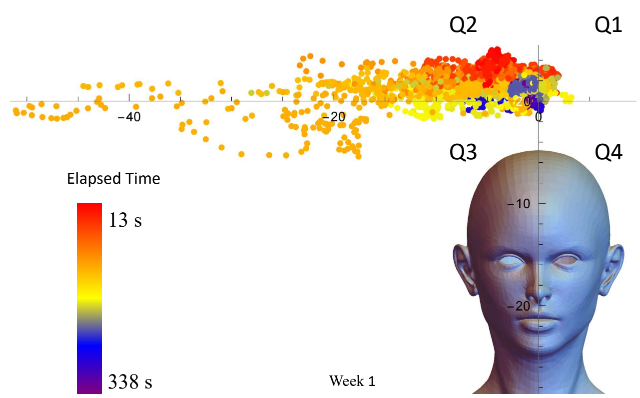

Fig. 2. Projections in the coronal plane of force vectors in Newtons captured at 36 Hz for Subject 3 during Week 1. Subject has a switch for access to a communication device on the right side. Head is included for visual orientation of vectors relative to the head only.

The endpoint of the force vector for each instant in time was plotted in three dimensions to show tendencies for direction and magnitude of pull (Figures 2, 3). The data in Figure 2 shows the subject pulling the head support to the right with a maximum force of approximately 50 N, while most of the points are central or to the right of center during Week 1 of data recording. Figure 3 shows data from Week 16, where the force reaches approximately 20 N to the left, with a maximum magnitude nearly 30 N. The data has shifted between Week 1 and Week 16 to have a higher density of points closer to the central axis and to the subject's left.

Figure 4 shows the percentage of time spent during each recording session in various force ranges, from 10%, 25%,

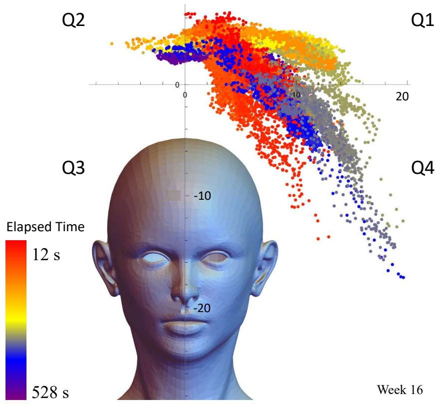

Fig. 3. Projections in the coronal plane of force vectors in Newtons captured at 36 Hz for Subject 3 during Week 16.

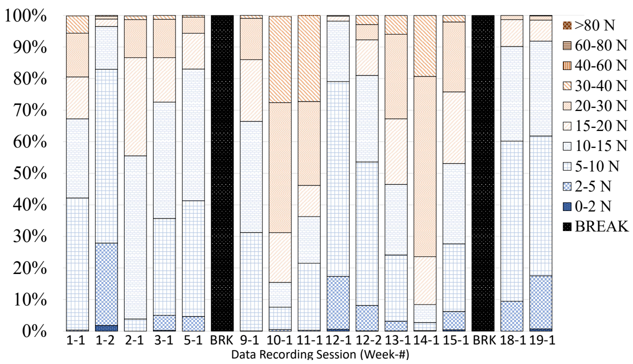

Fig. 4. Percentage of time spent in each force range during each separate data recording session (Subject 3)

50%, 75%, 100%, 150%, 200%, 300%, 400% of the approximate weight of the head (20 N) for Subject 3. The pattern is similar with each of the subjects, where the percentage of time in higher magnitude for ranges increases throughout the data collection. Each subject also has a period between Week 11-15 where the time spent in lower magnitude ranges was higher than the surrounding weeks.

Table I shows the percentage of time for forces greater than 10 N each subject had force activity over in each coronal plane quadrant. Each subject had at least one quadrant contain less than 1% of time during the first five weeks in that direction which increased to more than 5% of time during weeks 8-13 and 14-19.

IV. Discussion

When the therapists observed the subjects, they concluded that head control had improved. Data show increasing forces exerted on the head support throughout the course of the study, which can be seen in Figure 4. The higher magnitude of forces exerted indicates improved strength in muscles used in volitional and emerging, graded motions controlling the head. Over the course of the study, the subjects increased time spent in the Headpod and therapists observed more active, precise, and purposeful head movements.

The four participants had atypical development and acquisition of motor milestones (e.g. decreased prone propping skills, rolling) prior to this study that contributed to lack of strength in cervical power and poor head movements in all planes. Additionally, each subject has significant vision impairment, leading to reduced visual stimulus which can cause delays in motivation to move as the child does not learn to hold their head up while prone [14]. The head support used in an adapted seating device allows subjects to move their head more purposefully to permit visual searching. Subjects attempted lifting their heads without a head support but had limited sustained success. Clinical observations note that subjects actively moved their heads in all directions with the head support. The direction of the force vectors shifted from generally being more dense in one direction to having more frequent, stronger pulls in opposing directions. The density of points shifted to being more left dominant during Week 11 for Subject 3 (e.g. Week 16 in Figure 3). Table I shows each of the subjects using the head support to having more activity in at least one direction where they previously showed minimal activity. Subjects 1, 3, and 4 each had quadrants in the coronal plane with the highest percentage of time change to different quadrants between the first five weeks and the final weeks of data collection (Table I).

The subjects were engaged in performing typical classroom activities (e.g. gym, snack time, speech, OT/PT, group circle, free play) with adult support as needed. Their performance level varied according to their interest or preference in the activities during the time of data recording. For instance, subjects were noted to demonstrate an increase in active and purposeful head movement while in the head support as they visually and auditorily searched for teachers and peers who were in close proximity during school activities such as group circle or free playtime. The plots of the force vectors (Figure 2 is one example) showed the subjects producing more frequent and higher forces in the direction where the teacher was expected to be (based on their classroom seating placement recorded by data sheets provided to the teachers) as the study progressed.

TABLE I

Distribution of force directions greater than 10 N in quadrants in the coronal plane

	Weeks	Cumulative Time of Force Direction based on Quadrant (%)			
		Q1	Q2	Q3	Q4
Subject 1	1-4	64.07%	0.03%	12.23%	23.67%
	8-13	5.48%	13.87%	54.87%	25.78%
	14-16	6.36%	67.77%	25.72%	0.14%
Subject 2	1-4	0.00%	0.05%	99.57%	0.39%
	8-13	4.05%	14.58%	81.15%	0.21%
	14-18	4.26%	20.39%	74.61%	0.74%
Subject 3	1-5	8.02%	0.68%	62.72%	28.58%
	9-13	31.51%	1.37%	37.80%	29.32%
	14-17	60.34%	5.89%	14.16%	19.62%
Subject 4	1-4	0.20%	11.45%	86.75%	1.59%
	8-13	24.19%	22.55%	44.56%	8.70%
	14-19	9.01%	77.15%	13.60%	0.24%

Subjects' alertness and cognition improved as observed with the ability to use switches for choice making and activating toys for cause and effect learning. While in the head support, subjects 2 and 3 were able to use switches for access to communication devices and adapted toys using lateral motions of the head to press a button positioned on either side of their head. Utilizing the switches provided incentive for the subjects to make more controlled movements to activate switch adapted toys. Figure 2 is a data set where a switch connected to a communication device is positioned to the right of Subject 3. Using the head support for choice making opportunities with use of two head switches increased the subjects' participation in educational and social activities alongside peers.

Figure 4 provides insight as to how much the subject needs additional support or when the head suspension device may be providing resistance to the motions subjects are performing. Force ranges between 15 N-30 N could be where subjects show increasing volitional head movements. This may also indicate the strengthening of cervical muscles, providing a more stable base in the head for better visual stability (visual fixation), extraocular muscle function (visual tracking), and graded head movements. Visual and tactile searching become more readily available as visual stability and head control improve, which can lead to improved access for communication and social interaction.

Subject 3 is still unable to hold their head upright independently but has developed more active, purposeful head movement when using the head support. The subject rotates farther to reach the communication switches, and the positions of the switches were adjusted to encourage the subject to move out of their resting position throughout the study. Subject 3 has an asymmetrical head shape (plagiocephalic) that made resting on the right side of the head rest more typical for the subject initially and made turning the head over the protrusion of the occiput more difficult. This subject was able to rotate the head to the left more easily as cervical strength and control improved after using the head support. Figure 3 shows an example of the difference between Week 1 (more points on the subject's right side) and Week 16 (more points centered and on the subject's left side).

The second half of the data sets in Figure 4 for Subject 3 and equivalent plots for all subjects have a higher percentage of time spent with the head support maintaining more than 20 N. Force magnitudes greater than 40 N decreased during the last two weeks of the study, with one possibility being that the subject had developed some head control. Hypotonia and muscle weakness also lead to difficulty with isolated movements, which can increase difficulty to decelerate once a movement has been started [15]. Higher magnitude forces may be caused by the more poorly graded motions in a new direction, or the higher magnitude forces could be volitional movements showing continued strengthening of muscles.

Other outcomes of note were observed as well. More vocalizations were frequently heard and were often louder because breath support for speech is affected by positioning of the head and trunk. The head support and upright seating provided increased opportunities for subjects to interact with peers and provided social cues of head turning and visual focusing while interacting with peers.

V. Conclusions

This study was performed to track the change in forces exerted on a head support from children with cervical hypotonia. Subjects demonstrated more precise and active head movements throughout the study. Signs consistent with increased cervical strength were observed during data analysis.

One future application is to collect data used for this progress alongside data from a motion capture system to examine the musculoskeletal modeling of the cervical spine with an external head support. Motion capture data will help understand muscle excitation and forces in the cervical spine with the forces from a head support. Other observations included the importance of vision in facilitating movement and control of head positioning. Future research focusing on the relationship between vision and head control could lead to better rehabilitation techniques.

References

[1] M. Arroyo Noriega and L. L. Jaunsarás, "Effects of a new dynamic head suspension device in feeding people with loss of head control.," 2013.

[2] J. E. Brown, M. Thompson, and K. Brizzolara, "Head Control Changes after Headpod Use in Children with Poor Head Control: A Feasibility Study," *Pediatric Physical Therapy*, 2018.

[3] H.-M. Lee and J. C. Galloway, "Early Intensive Postural and Movement Training Advances Head Control in Very Young Infants," *Physical Therapy*, 2012.

[4] M. A. Velasco, R. Raya, L. Muzzioli, D. Morelli, A. Otero, M. Iosa, F. Cincotti, and E. Rocon, "Evaluation of cervical posture improvement of children with cerebral palsy after physical therapy based on head movements and serious games," *BioMedical Engineering Online*, 2017.

[5] W. G. Wright, M. R. Agah, K. Darvish, and E. A. Keshner, "Head stabilization shows visual and inertial dependence during passive stimulation: Implications for virtual rehabilitation," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 2013.

[6] S. Y. Chu and S. M. Barlow, "A Call for Biomechanics to Understand Hypotonia and Speech Movement Disorders in Down Syndrome," *Advances in communication disorders*, 2016.

[7] R. Raya, R. Ceres, J. O. Roa, and E. Rocon, "Assessment of the involuntary motion of children with motor impairments to improve the accessibility of an inertial interface," in *9th International Conference on Interaction Design and Children*, 2010.

[8] D. E. Peredo and M. C. Hannibal, "The floppy infant: Evaluation of hypotonia," *Pediatrics in Review*, 2009.

[9] "Siesta Systems."

[10] J. Brown, *Measuring head control changes after utilization of the headpodtm in children with poor head control.* PhD thesis, 2018.

[11] D. L. Damiano, K. Dodd, and N. F. Taylor, "Should we be testing and training muscle strength in cerebral palsy?," *Developmental Medicine and Child Neurology*, 2002.

[12] R. Palisano, P. Rosenbaum, S. Walter, D. Russell, E. Wood, and B. Galuppi, "Development and reliability of a system to classify gross motor function in children with cerebral palsy," *Developmental Medicine & Child Neurology*, 2008.

[13] W. Goldsmith and J. Plunkett, "A biomechanical analysis of the causes of traumatic brain injury in infants and children," 2004.

[14] V. Bishop, *Infants and Toddlers with Visual Impairments*. Texas School for the Blind and Visually Impaired, 1998.

[15] F. Ferrari, H. F. Prechtl, G. Cioni, M. Federica Roversi, C. Einspieler, C. Gallo, P. B. Paolicelli, and G. B. Cavazzuti, "Posture, spontaneous movements, and behavioural state organisation in infants affected by brain malformations," *Early Human Development*, 1997.