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# An Analysis of a New Shoe Technology in The Gait Patterns of a Child with a Neurological Disability

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## Cover Page Footnote

I would like to thank Dr. Timothy Davis for allowing myself and Dr. Jeff Bauer to use his laboratory to conduct this study. I would also like to personally thank Dr. Bauer in his guidance through the process of planning, conducting, and writing the paper regarding this research. Lastly, thank you to my family and friends for the continued support.

## Introduction

Cerebral Palsy (CP) is characterized as one of the most common motor disabilities of childhood; which causes disturbances in sensation, perception, cognition, communication, behavior, and musculoskeletal problems (Rosenbaum, Paneth, Leviton, Goldstein, & Bax, 2006; Christensen et al., 2014). CP is caused by abnormal brain development or damage to the developing brain tissue which can cause a lack of control of a child's muscles (Centers for Disease Control and Prevention, 2019). There are four primary types of CP: spastic CP, dyskinetic CP, ataxic CP, and mixed CP. Spastic cerebral palsy is usually described by what parts of the body are affected in certain individuals and include spastic diplegia, spastic hemiplegia, and spastic quadriplegia. Diplegia is where the muscle stiffness is mostly in the legs and with arms experiencing little or no effect. Hemiplegia affects only one side of a person's body, much like a stroke victim, typically effecting arms more than legs. Spastic quadriplegia is the most severe form of spastic CP and affects all four limbs, the trunk, and the face. Typically, those with spastic quadriplegia have difficulty with ambulation often requiring assistance and commonly present with comorbidities of developmental disabilities, vision, hearing, or speech delay (Centers for Disease Control and Prevention, 2019).

Many individuals with CP struggle with ambulation and a common goal is to improve their gait function. Improving gait function in these children, allows them to be more independent and social in their daily life (Lepage, Noreau, & Bernard, 1998; Bjornson et al., 2007). This is an especially important goal for those with spastic quadriplegia CP since there is a much higher likelihood of requiring some form of assistance to walk. It is estimated that 58.2% of children with CP are classified at a Gross Motor Function Classification System (GMFCS) Level I or II, thus indicating that they are independently ambulant (Christensen et al., 2014). 11.3% of children with CP walk while using a hand-held assistive device and are at GMFCS Level III. Additionally, 30.6% of children with CP have a limited or an absence of ambulatory ability and are at GMFCS Levels IV and V (Christensen et al., 2014). Children with CP also have a high possibility of walking on their toes or having an in-toeing equinus gait pattern, which limits the child's control and stability and can lead to more falls (Rethlefsen, Blumstein, Kay, Dorey, & Wren, 2016). Additionally, because of the insufficient loads near the hind foot and more pointed at the forefoot, underdevelopment of the heel bone is common (Pendharkar, Percival, Morgan, & Lai, 2012). As a result, gait training is essential for all levels of children with CP in order to introduce proper gait patterns and avoid unnecessary injuries to the hindfoot. However, gait training often requires a significant time commitment by the child and by extension their caregiver(s). This is why new ways to make gait training more fun and enjoyable are necessary.

Biofeedback systems have been widely recognized as being beneficial in gait rehabilitation for adults and children with CP. Feedback systems often utilize visual, auditory, or tactile information to help the individual monitor or manage their gait. It is known that neuroplasticity in the brain and improvement of motor function can be obtained through mechanisms of repetitive tasks like those in feedback systems (Kleim & Jones, 2008). An auditory feedback system was originally developed by Conrad and Bleck which was based on a pressure-sensitive foot switch to help correct the toe-walking in those with CP (Conrad & Bleck, 1980). The system would be triggered if a toe-walking stride was detected in the gait cycle (Conrad & Bleck, 1980). Other studies are using feedback in the form of virtual reality (VR) (Booth et al, 2018; Cho, Hwang[1], Hwang[2], & Chung, 2016; Gelder et al, 2017; Baram & Lenger, 2011). VR can utilize forms of feedback like visual and auditory (Booth et al, 2018; Baram & Lenger, 2011). In one study the researchers used VR to see if children with CP are capable of adjusting their gait pattern in response to real-time visual feedback and achieve better extension of the hip and knee. They found that all the children in the study except for one were able to achieve some improvement in the hip and knee joints (Gelder et al, 2017). Another study used VR with 3 clinically relevant gait parameters: step length, knee extension in late swing, and ankle power generation. They found that the children in the VR environment were able to improve all three gait parameters with acute biofeedback from the VR system (Booth et al, 2018).

Our study is based on a system that integrates pressure sensors with an auditory stimulus that is triggered when there is a heel or toe touch. The Electroskip$^{TM}$ system utilizes pressure insole sensors that generate a sound/beat/song when a compressive force under the heel or toes exceeds a specified threshold. The sounds/beats/songs can be changed according to the choice of the user. While active, the Electroskip$^{TM}$ system can record the amount of heel or toe strikes as well as when the heel or toe load is increasing or decreasing. Additionally, the system can measure the amount of pressure that an individual is exhibiting in a heel or toe strike. However, in this case study we did not analyze the pressure values generated by the child as reported by the technology due to the inconsistency of the pressure readings. This technology may also utilize a motivation tactic to encourage children with CP to be more willing to engage in gait training. The technology was originally designed to help dancers to create their own music, but is now being looked at as a more clinical tool.

This study reflects the meaning of applied learning in the sense of academic undergraduate research. The SUNY definition for applied learning states that applying the skills and knowledge obtained in the classroom to another setting, which in this case is structured research (SUNY, 2020). In this study, skills of multiple disciplines like biomechanics, anatomy, and motor behavior were learned in the classroom and applied to this study. For example, the learned aspects of how to manage various technological devices such as Electroskip$^{TM}$, video cameras, various computers, and software's, as well as understanding varying gait patterns was learned in biomechanics. The basic anatomy of the human body and an understanding of the ailments that come with a neurological disorder was learned in anatomy, motor behavior, and biomechanics. Skills like knowing how to conduct research were learned in research methods courses and then expanded upon in this research.

The purpose of this case study was to determine if using Electroskip$^{TM}$ technology would increase the overall movement patterns of a child with Cerebral Palsy. We hypothesized that the child would take more steps and would complete the walking tasks faster when the Electroskip$^{TM}$ system was active compared to when the Electroskip$^{TM}$ was inactive.

## Materials and Methods

The study was approved by the State University of New York College at Cortland Institutional Review Board. Written informed consent was obtained from the child's parents, as well as an assent form that was read off to the child before the child participated in the study. Our participant was previously working in the college's Sensory Integration Motor lab (SIM's Lab), and with the help of his parents volunteered for our study.

### Case Presentation

The participant was a soon to be 5-year-old boy who was born with quadriplegic spastic cerebral palsy. The child had difficulty with body control and speech. At the onset of the study, the child was still working in the Sensory Motor Integration Laboratory and had been evaluated by Dr. Timothy Davis using the Test of Gross Motor Development II (TGMD-II) (Centers for Disease and Prevention, 2012). The TGMD-ll measures both locomotor and object control of an individual. The child was also retested at the completion of the study. The child demonstrated before the study started that he was able to walk short distances with the help of his posterior walker and/or his parent's assistance. There were no inclusion criteria to be in this case study beyond the child's ability walk a short distance. At the time of participation, the child had previously received five Botox treatments and was currently in a stem cell injection trial.

Gait Intervention

The technology used for the gait intervention was Electroskip$^{\text{TM}}$, but for this study we utilized a pre-market Electroskip$^{\text{TM}}$ prototype. This is a system that utilizes biofeedback predicted on force being exerted on the heel or toe leading to a sound/beat/song being emitted from the device. The system consists of small light weight devices strapped to the top of an individual's shoes (see figure 1). There are 8 different sounds/beats/songs that can be chosen while using the technology.

Figure 1: Electroskip$^{\text{TM}}$ shoe with the transceiver on top, and Electroskip left shoe with the Tekscan

sensors on the insole to the right and transceiver to the left.

## Instrumentation and Procedure

The participant completed 12 trainings over the 6-week period. One session a week was with the Electroskip$^{TM}$ technology active and during the other sessions it was inactivate. During each session, the child would come into the laboratory and would have the Electroskip$^{TM}$ shoes put on by the researcher. The purpose of putting the shoes on the child with the Electroskip$^{TM}$ transceiver every time was to have consistency in the sessions for the child. The child would then be instructed to move to where a set of customized parallel bars were placed for him to walk through for his pre-walk test. Once the child reached the parallel bars and was ready to walk, the researcher would begin data recording. While the child was walking the researcher would note the child's motivation level that day and then noted which sound the child wanted to hear while they walked. The motivation levels were assigned by the researcher based on a five stage Likert scale to assess motivation (Table 1). Additionally, the Electroskip$^{TM}$ technology would be recording the amount of heel and toe strikes that the child produced in each walk. Each trial was also recorded on video which would be used by the researcher to count heel and toe strikes to compare to the Electroskip$^{TM}$ system output. Upon completion of the straight-line walking, the child would have a period of free play in the SIMs lab. This time was used to help the child be able to relax and get additional vestibular training in with Dr. Davis. After the planned sensory motor activity, the child would return to the parallel bars for the post-test walking. The child would repeat the same procedure as the pre-test and would walk as far as they could. Each session ranged from 30 to 45 minutes in duration.

*Table 1: Motivational scale created by the researcher.*

| Motivational | Description |
|---|---|
| 1 | Very bad |
| 2 | Bad |
| 3 | Neutral |
| 4 | Good |
| 5 | Excellent |

## Results

Wilcoxon nonparametric paired T-tests were run using JASP statistical software to determine if there was any significant difference between the number of heel and toe strikes, and time to completion of the walking tasks recorded per session by the Electroskip$^{TM}$ system and video system between the active and inactive Electroskip$^{TM}$ conditions. Additionally, this data was gathered from both the Electroskip$^{TM}$ software and from the video data obtained during the sessions. The data displayed is from just one walk down the test platform that the child did with pre and post walking. There was no significant difference between the number of steps that the child took or the time of completion between the active versus inactive Electroskip$^{TM}$ conditions. Tables 2-7 show the Electroskip$^{TM}$ data and video from all sessions in relation to number of steps and time of completion. Additionally, the child was tested by Dr. Davis using the Test of Gross Motor Development II (TGMD-II) at the beginning and end of the study. Initial TGMD-II results indicated that the child could walk a distance of two feet with assistance and support of a walker and hand support under both arms. After the completion of the study, the child was able to walk 8 feet unassisted with the help of parallel bars and no longer needed the support under both arms.

*Table 2: Number of steps taken for all of the sessions from Electroskip$^{TM}$ and video data.*

| Collection Type | N | Mean | SD | SE | P-Value |
|---|---|---|---|---|---|
| Pre-Step Electroskip | 11 | 46.1 | 22.8 | 6.9 | 0.426 |
| Pre-Step Video | 12 | 44.3 | 12.8 | 3.7 | 0.476 |
| Post-Step Electroskip | 10 | 59.6 | 61.7 | 19.5 | 0.426 |
| Post-Step Video | 11 | 54.5 | 48.8 | 14.7 | 0.476 |

*Table 3: Number of steps taken for sessions with Electroskip$^{TM}$ active with Electroskip$^{TM}$ and video data.*

| Collection Type | N | Mean | SD | SE | P-Value |
|---|---|---|---|---|---|
| Pre-Step Electroskip | 5 | 60.2 | 21.0 | 9.4 | 0.750 |
| Pre-Step Video | 6 | 50.3 | 13.4 | 5.5 | 0.855 |
| Post-Step Electroskip | 4 | 84.3 | 97.3 | 48.6 | 0.750 |
| Post-Step Video | 5 | 77.0 | 68.5 | 30.6 | 0.855 |

*Table 4: Number of steps taken for sessions with Electroskip$^{TM}$ inactive with Electroskip$^{TM}$ and video data.*

| Collection Type | N | Mean | SD | SE | P-Value |
|---|---|---|---|---|---|
| Pre-Step Electroskip | 6 | 34.3 | 17.9 | 7.3 | 0.438 |
| Pre-Step Video | 6 | 38.2 | 9.5 | 3.9 | 0.057 |
| Post-Step Electroskip | 6 | 38.7 | 13.2 | 5.4 | 0.438 |
| Post-Step Video | 6 | 35.7 | 8.8 | 3.6 | 0.057 |

*Table 5: Time of completion for all of the sessions with Electroskip$^{TM}$ and video data.*

| Collection Type | N | Mean (s) | SD | SE | P-Value |
|---|---|---|---|---|---|
| Pre-Time Electroskip | 11 | 72.6 | 24.9 | 75.1 | 0.570 |
| Pre-Time Video | 11 | 77.8 | 22.7 | 6.8 | 0.492 |
| Post-Time Electroskip | 10 | 87.7 | 82.5 | 26.1 | 0.570 |
| Post-Time Video | 10 | 87.2 | 77.2 | 24.4 | 0.492 |

*Table 6: Time of completion for sessions with Electroskip$^{TM}$ active with Electroskip$^{TM}$ and video data.*

| Collection Type | N | Mean (s) | SD | SE | P-Value |
|---|---|---|---|---|---|
| Pre-Time Electroskip | 5 | 88.9 | 27.9 | 12.5 | 0.750 |
| Pre-Time Video | 6 | 91.0 | 21.3 | 86.8 | 0.625 |
| Post-Time Electroskip | 4 | 125.2 | 130.2 | 65.1 | 0.750 |
| Post-Time Video | 5 | 111.6 | 65.1 | 484.3 | 0.625 |

*Table 7: Time of completion for sessions with Electroskip$^{TM}$ inactive with Electroskip$^{TM}$ and video data.*

| Collection Type | N | Mean (s) | SD | SE | P-Value |
|---|---|---|---|---|---|
| Pre-Time Electroskip | 6 | 58.7 | 118.2 | 4.8 | 0.844 |
| Pre-Time Video | 6 | 60.3 | 11.7 | 4.8 | 0.563 |
| Post-Time Electroskip | 6 | 63.6 | 14.8 | 6.0 | 0.844 |
| Post-Time Video | 6 | 64.3 | 12.6 | 5.1 | 0.563 |

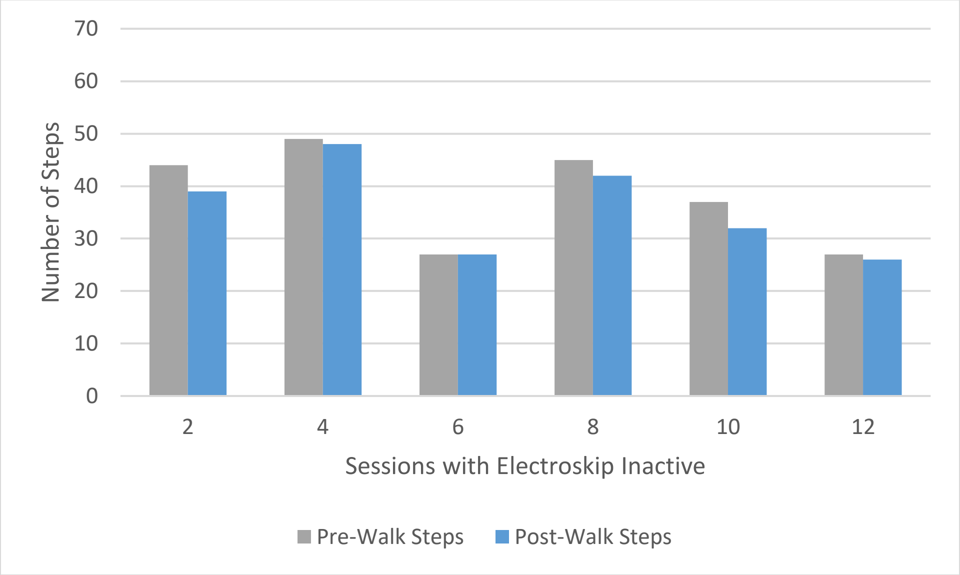

*Figure 2: Number of steps taken in sessions with Electroskip$^{TM}$ inactive using video data.*

## Discussion

The hypothesis that the child would take more steps and would complete the walking tasks faster when the Electroskip$^{TM}$ system was active compared to when the Electroskip$^{TM}$ was inactive, was not supported by the data. Electroskip$^{TM}$ and video data related to the number of toe and heel strikes, and time of completion of walking tasks, were not statistically different. The Electroskip$^{TM}$ generated data and video data were both used in order to ensure that the two data sets provided similar results. The system is just making its debut into the clinical world, so it was necessary to make sure that the Electroskip$^{TM}$ system was outputting reliable data. The researcher compared the number of steps between the Electroskip$^{TM}$ system to video data to determine the accuracy of measurement of the Electroskip$^{TM}$ outputs. Additionally, the study was a mere 6 weeks long in which it is very hard to see progress in that short time span. In table 4, it is observed that number of pre-steps with video data while Electroskip$^{TM}$ is inactive is almost significant ($p = 0.057$). The rationale for why there was almost a significance in video data, but not the Electroskip$^{TM}$ data, is that the Electroskip$^{TM}$ system sometimes had glitches in the system which is partly due to the Tekscan sensors that were being used with the system. This trend that took place in the pre-step video data while Electroskip$^{TM}$ was inactive can be viewed in figure 2. In tables three and four there are some discrepancies between the pre and post number of steps, but not a big enough difference to be significant. The reasoning for this pattern could be that the child was simply viewing the Electroskip$^{TM}$ as a means of making sounds, rather than motivating the child to have a proper gait pattern. The Electroskip$^{TM}$ technology was providing a motivational tactic to get the child to move, but was also a distractor due level of maturity of the child. The child focused more on the cause and effect relationship between tapping their foot and making a sound, rather than focusing on properly walking. This is noted as a potential issue with technologies like virtual reality (VR) (Booth et al, 2018). It is often hard for these children to focus in on the task at hand like walking and not an external stimulus like an avatar, or in our case the Electroskip$^{TM}$ sounds

(Booth et al, 2018). Having a cause and effect relationship is not necessarily a bad thing, since often times rehabilitative gait training can be monotonous, so having ways to make it more interesting is always beneficial. VR is used to help with motivation and keeping children focused on the task, similar to the goal of the Electroskip$^{TM}$ in this study (Booth et al, 2018). Other studies have implemented real time gait kinematic feedback with VR, which tells the children how to properly execute their gait pattern (Gelder et al, 2017; Booth et al, 2018). Additionally, some VR has avatars implemented so that the children can have a visual reference to follow (Booth et al, 2018; Cho, Hwang[1], Hwang[2], & Chung, 2016; Gelder et al, 2017; Baram & Lenger, 2011). However, we were trying to see if the technology itself could get the child to walk better without other outside cues. The child progressed in the aspect of being able to move more than he could at the beginning of the research as shown in the TGMI-II evaluation from Dr. Davis. The child went from walking two feet fully assisted to eight feet with no assistance except for the parallel bars. However, it was impossible to determine if this improvement was caused or assisted by the Electroskip$^{TM}$ training, increased comfort level with his new environment or was a result of other factors such as the stem cell and Botox injections given to the child around the of his participation in our study. This shows similar trends to other research that expressed that children with CP have exhibited an ability to adapt to changes in their gait patterns with different forms of feedback, rather than having a very rigid gait (Gelder et al, 2017). Additionally, the data may not show a significant improvement, but as the sessions progressed the child was walking more than when the sessions first started. When the study first started, the child only walked down one way, but as it progressed the child would walk down and back. Though we did not find a significant difference in the number of steps the child was taking with or without Electroskip$^{TM}$, the child as well as their parents enjoyed the experience. In a study with a home-based treadmill program to help with the gait parameters of children with CP, they also found that the children and parents enjoyed the experience and it was suitable for a child with quadriplegic CP (Kenyon et al, 2017).

Our second hypothesis that the child would finish the walking task faster when the technology was active versus inactive was not supported by our data. As shown in tables 6 and 7 there are differences in time of completion between when the technology was active or inactive across all sessions when looking at the pre and post walk, but not a significant difference. This is true in relation to using both the Electroskip and video generated data. The rationale for this hypothesis was that it was thought that the child would be even more motivated by the technology that it would push him to move faster. A scale of motivation was created by the researcher to be able to gauge the motivation level of the child each day, but this was not a scale that had previously been tested (Table 2). With that being said statistics were not run on the motivation, but it was observed that the child was moderately the same mood wise if Electroskip$^{TM}$ was active or not. Some days the child may not have been motivated with Electroskip$^{TM}$ active, because they were simply not in the mood regardless of the sounds, which is often common in children around four and five. There were some days that if the child was feeling great and was in a good mood, the child would walk even without the sounds. However, on days that the child was in a bad mood, the sounds did not make a difference. The researcher observed that the child would often get excited with the Electroskip$^{TM}$ sounds and would move faster toward the finish line of the walk, but not a significant amount more than when Electroskip$^{TM}$ was inactive, as shown in tables 6 and 7. Additionally, with a child of this age, they may not have realized the importance of time or rather even cared how long it took them to finish each task. The goal was not for the child to finish the walking task very fast, but to see if their cadence increased over time or between pre and post testing with Electroskip$^{TM}$ active versus inactive. Although the time of completion of the walking tasks was not significantly different with Electroskip$^{TM}$ active versus inactive, it is clearly shown that Electroskip$^{TM}$ motivated the child to move even when the sounds were not on. Further investigation of why the child could have responded positively to just having the Electroskip$^{TM}$ shoes on but not active would be need to be studied further.

## Study Limitations

The ultimate success of the Electroskip$^{TM}$ system and biofeedback systems at this time are still unknown. This study aimed to see if a child with CP would walk better with the sounds generated from the system, but there are limitations. One of which included the time frame of the study, where the child was transitioning from being 4 to 5 years old. Additionally, the study was only 6 weeks long which is not a long enough time frame to see sufficient changes. It is recommended that if this study is done again to potentially double the time and number of sessions. This study also used a child who not only has CP but has the most debilitating form; spastic quadriplegia, which could have caused the lack in results. Many other studies that included individuals with CP used participants who have a less severe case of CP (Booth et al, 2018; Gelder et al, 2017; Baram & Lenger, 2011; Cho, Hwang[1], Hwang[2], & Chung, 2016; Rethlefsen, Blumstein, Kay, Dorey, & Wren, 2016; Pendharkar, Percival, Morgan, & Lai, 2012). The child also had Botox injections prior to the start of the study which may have had an influence on the results of the study. The child was also enrolled in a stem cell treatment through Duke University. Additionally, this study only looked at a few gait parameters like the number of steps and time of completion. There was also not a Gross Motor Classification System used that some studies have done, however Dr. Davis conducted a clinical evaluation using the TGMD-II (Rethlefsen, Blumstein, Kay, Dorey, & Wren, 2016; Gelder et al, 2017; Booth et al, 2018). There was also the use of buzzers during some sessions of the study to motivate the child further to walk to the end of the parallel bar platform, which could have affected our results as well.

## Conclusion

This case study, having only one participant, does not allow for enough data to make broad generalizations, but Electroskip$^{TM}$ may have the potential to help those with CP and other neurological disorders like Parkinson's disease (PD). It is possible that the child who was in the study did not have enough of a relationship with the stimulus (music) to be able to really make an effect. It was noticed by the researcher that the child developed more of a cause and effect relationship with the Electroskip$^{TM}$ technology, which could account for the outcome of the study. However, those with PD may benefit more from the system since they most likely have more of a connection with music and have a gait pattern that was previously established earlier in life. Gait training with the Electroskip$^{TM}$ system should be studied further and more parameters like step length, elevation at midswing, and number of steps should be examined. Additionally, as the Electroskip$^{TM}$ system progresses it would be suitable to customize the shoes to play different sounds when properly walking or not. It would also be ideal to use Electroskip$^{TM}$ in conjunction with auditory feedback on proper gait execution from a movement specialist like a Physical Therapy or Biomechanist.  It is believed that as the Electroskip$^{TM}$ system improves its design will be much more suitable for the clinical world.

This research is an example of how undergraduate research can be used as a source of applied learning. The course work that was taken by the researcher allowed for a greater understanding of the biological functions of the human body coupled with the learned skills of movement sciences from courses like biomechanics, motor behavior, and exercise physiology in order to understand the function of the child in the research. Additionally, the research classes taken provided a ground work for the researcher to be able to formulate their own study. Future applied practitioners can use this research as an example to build off of in the realm of movement sciences, or see it as an example of extracting information from the classroom and using it in real life work.

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