Torque3 Functional Assurance Evaluations
Case Reports

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Abstract

Stroke is a leading cause of disability worldwide. Torque3 has developed a therapeutic platform that aims to address unmet needs in neurorehabilitation. The company recently conducted two Functional Assurance Evaluations, or FAEs, to demonstrate the safety and reliability of the platform. As part of this evaluation, clinical measures were conducted on the 6 participants involved. The results demonstrated that the Torque3 platform produced clinically meaningful improvements, in plateaued patients as demonstrated by 1) improved neurocognitive function, 2) improved physical therapy measures, 3) improved psychological functioning, 4) improved activity of daily living tasks, and 5) improved subjective experience of wellbeing and meaningfulness of life. An unexpected outcome was that these improvements were achieved in extremely short timescales of 8 weeks. Furthermore, the improvements were maintained after the participants had completed testing. We present the results from our 6 participants below.

Introduction

Stroke is a leading cause of disability, with a stunning 80 million stroke survivors globally. Task Oriented Therapy is the standard of care for neurorehabilitation. Stroke survivors may have impairment in several domains. Two of the most severe impairments are weakness or paralysis on one side of the body, or *hemiplegia*, and unilateral loss of spatial perception, or *hemispatial neglect.* Current practices focus on one impairment at a time rather than working the entire body in a holistic fashion. We contend that this focus on only the impaired side of the body limits therapeutic effectiveness.

One sometimes overlooked result from stroke is *hemispatial neglect.* Neglect means one is unaware of the left or right space through which they must *orient* themselves and *navigate* through the world. This is not a defect in sight, but rather a lack of spatial perception that results from damage in certain parts of the brain. Depending on the site of the lesion, they may not even recognize their limitations. Unfortunately, many people have both hemiplegia and hemispatial neglect. Our approach addresses these deficits by creating a system that compensates for unilateral impairment and maximizing successful recovery as discussed below.

Torque3 has developed a robotic-assisted, deeply immersive simulator that simultaneously engages a patient's muscles, senses, and cognitive abilities during treatment. This experience-dependent, multimodal integration activates numerous brain regions; including but not limited to sensory, association, and motor cortices, thereby increasing reparative neuroplasticity at or near the site of injury.

Our simulation platform creates an experience that is constantly new, challenging, and brings in the element of 'play'. It assigns urgency and importance to performing certain tasks such as navigating away from a boulder or tree, so one doesn't 'crash' into it. We accomplish all this with a suite of simulation technologies that operate as an integrated stroke rehabilitation system using our proprietary hardware and software. The entire platform is computer-controlled using state-of-the-art sensors, video game technologies, and utilizes adaptive robotics to create a seamless, immersive experience.

Cycling is a mainstay for stroke rehabilitation. Unfortunately, during cycle training, the unaffected limb tends to compensate for the affected one, which results in asymmetrical muscle activation and suboptimal rehabilitation. Cycling requires participants to move both of their lower limbs alternately with equal force, but, for hemiparetic patients, the unaffected limb often compensates for the lack of activation in the affected limb. The unaffected limb may mask the weakness of the affected limb and result in uncoordinated training, which may reduce potential benefits and intensify gait dissymmetry of the hemiparetic patient resulting in poorly integrated neural reorganization.

Our platform aims to address this by using the unimpaired side of the body to regulate the activity of both limbs with real-time, adaptive algorithms that drive interlinking of the pedals. The robotics sense the effort being applied by the unimpaired side and compensate for the weakness on the impaired side – this forces the weak side of the body to work harder, but in a way that is fun and exciting. The robotic component of the platform envelops the patient and keeps them secured.

Once the virtual reality sensory systems are engaged, the recumbent bike is transformed into a virtual quadracycle, from which the rider enters a natural space. The rider experiences being fully present in the immersive simulated world and experiences the illusion that they have a different body. That is, they will have a sense of "embodied presence". Fully embodied, when they look down towards their physical body, they see a virtual body or avatar, that is spatially coincident with their real body. The physical body sitting on a recumbent robot is "transformed", and the rider becomes the avatar who is riding a quadracycle through a virtual simulated world. It is the avatar that navigates through the virtual world, not the real-world, physical person. In our system, one can be secured to the platform in the real environment while safely taking risks in the simulated one. No other available rehabilitation system can do this.

Functional Assurance Evaluations

Overview

We recently conducted two formal assessments of our system that we called Functional Assurance Evaluations, or FAEs, meaning that the goals of these assessments were to ensure that the system functioned safely and as intended. The FAEs were conducted in 2 phases with enhancements made to the system based on Phase 1 results prior to proceeding to Phase 2.

Patient Cohort – Plateaued Patients

To conduct this assessment, we recruited 6 stroke survivors between 50 to 60 years old. Four of them were male, and two were female. **Each had completed their rehabilitation, had been considered "plateaued," and told they should expect no further improvement**.

Additional Testing Objectives

In addition to collecting platform-based data, we also collected clinically meaningful data on physical, psychological, cognitive, and functional measures before, during, and after each FAE Phase. Each assessment was conducted over an 8-week period, with 5 sessions a week that lasted approximately 40-50 minutes each. There was a 2-month gap between Phase 1 and Phase to allow for system enhancements.

Testing Sessions Overview

During sessions, the riders participated in a variety of experiences in several distinct and naturalistic immersive worlds that we call "Zens". These experiences required them to orient and navigate through complex spatial environments while receiving continual visual, auditory, somatosensory, and physical feedback.

For example, they received visual feedback via a virtual reality headset, auditory feedback through noise-canceling headphones, somatosensory feedback via dynamic wind simulation and motion platform movement, and physical feedback of the terrain they were riding on through the pedals and steering blades. Throughout every experience, the rider had to engage both upper and lower extremities while being enveloped in a multisensory world.

Within these virtual worlds, they were able to perform activities 'as if' they were unimpaired because of the asymmetrical compensation feature of the platform. Activities included both navigating natural trails and performing specific cognitive and motor tasks that required integration of cognition, motor strength, and motor coordination.

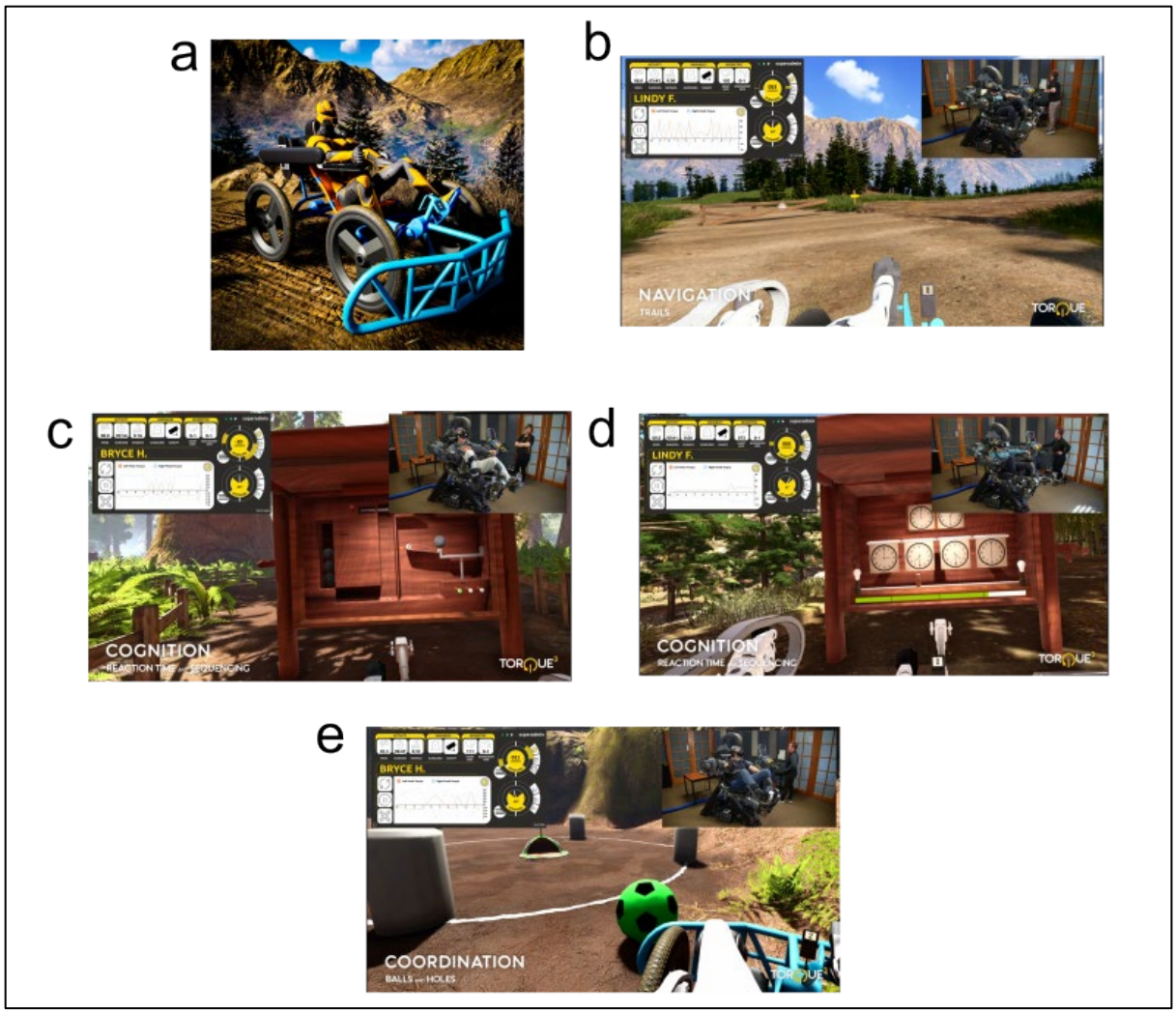


Figure 1. Torque3 immersive simulator experience for FAE Phase 1. a. Avatar of virtual rider from a third-person perspective. b-e. Game types: Trails (b), reaction time (c), sequencing (d), and balls and holes (e) game modes.

Participants navigated trails specifically designed to challenge the neurological and motor capabilities mentioned above.

For Phase 1, they also participated in several "tasks" or "games" including:

1) Reaction Time: redirecting a ball through a rider-controlled pedal.
2) Sequencing: solving a pattern of clocks, calendars, states of aging, etc.
3) Balls in Holes: tested coordination, navigation, and problem-solving by playing a mini-golf-like game that required the rider to direct a large ball into a large hole using the quadracycle as the "putter".

For Phase 2, these games were converted to naturalistic challenges that were imbedded within each Zen in a manner imperceptible to the rider. This had the benefit of *not breaking immersion.* We contend that remaining immersed does not only help one complete motor exercises but is therapeutic in and of itself.

Assessment Measures

Each participant concluded all 40 sessions of the FAE and assessment measures were administered before, during, and after the 8-week assessment. The participants differed in pathology and presentation, but all had some degree of hemiplegia and hemispatial neglect. The platform evaluation included mechanical measures, incident analysis, as well as safety and potential simulation side-effects.

Measures of physical functioning included standard physical therapy assessment for strength, balance, range of motion, sensory perception, and gait. In the first phase of our FAEs, participants provided measures from their private therapists who used their own favored tests. They were, therefore, difficult to compare with one another.

For Phase 2 on the other hand, we had one, non-company physical therapist conduct all tests in a standardized measure that allowed more accurate outcome comparisons. Physical therapy measures for Phase 2 included:

Timed Up and Go test (TUG)

- Measures mobility and requires both static and dynamic balance. It uses the time that a person takes to rise from a chair, walk three meters, turn around 180 degrees, walk back to the chair, and sit down while turning 180 degrees. The time it takes for a participant to walk around an object and back to their seat, is represented in seconds. The higher the score, the greater the risk of falling.

Berg Balance Scale (Berg)

- Measures balance and risk of falling. It includes 14 balance-related tasks and takes about 20 minutes. The higher the number, the better the person's balance. Maximum score of 56. Results are represented by a percentage.

Dynamic Gait Index (DGI)

- Tests the ability to maintain walking balance while responding to different task demands, through various dynamic conditions. It is a useful test in individuals with vestibular and balance problems and those at risk of falls. Scoring: A four-point ordinal scale, ranging from 0-3. "0" indicates the lowest level of function, and "3" is the highest level of function.

Lower Extremity Motor Coordination Test (LEMCOT)

- Assesses, measures, and evaluates the deficits in lower limb motor coordination, specifically spatial and temporal accuracies in dominant and non-dominant limbs. The score is determined by a calculation of discrete variables.

Five Times Sit to Stand Test (5STS)

- Measures functional lower extremity strength and/or identifies movement strategies a patient uses to complete transitional movements.

Psychological measures included screening for depression (*PHQ-9*), and anxiety (*GAD-7*). Real-world functioning was assessed using the *Patient Functional Assessment Questionnaire (PFAQ)* which assesses functioning in four domains including 1) Mobility / Walking, 2) Maintaining Body Position, 3) Handling/Moving Objects, and 4) Self Care.

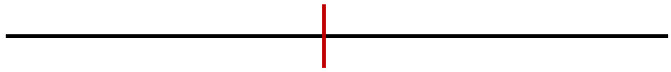
PATIENT FUNCTIONAL ASSESSMENT QUESTIONNAIRE

PATIENT NAME: _____ **DATE:** _____

		INSTRUCTIONS: Circle the level of difficulty for each activity.	0 = Absolute no difficulty	1 = Able to do w little difficulty	2 = Able to do w lit-mod difficulty	3 = Able to do w mod difficulty	4 = Able to do w mod-signif difficulty	5 = Able to do w signif difficulty	6 = Unable to do at all	Not applicable
MOBILITY/WALKING	1	Walking short distances	0	1	2	3	4	5	6	n/a
	2	Walking long distances	0	1	2	3	4	5	6	n/a
	3	Walking outdoors	0	1	2	3	4	5	6	n/a
	4	Climbing stairs	0	1	2	3	4	5	6	n/a
	5	Hopping	0	1	2	3	4	5	6	n/a
	6	Running	0	1	2	3	4	5	6	n/a
CHANGE/MAINTAIN BODY POSITION	1	Rolling over	0	1	2	3	4	5	6	n/a
	2	Moving - lying to sitting	0	1	2	3	4	5	6	n/a
	3	Sitting	0	1	2	3	4	5	6	n/a
	4	Bending/Stooping	0	1	2	3	4	5	6	n/a
	5	Kneeling	0	1	2	3	4	5	6	n/a
	6	Standing	0	1	2	3	4	5	6	n/a
CARRY/MOVE/ HANDLE OBJECTS	1	Pushing	0	1	2	3	4	5	6	n/a
	2	Pulling	0	1	2	3	4	5	6	n/a
	3	Reaching	0	1	2	3	4	5	6	n/a
	4	Grasping	0	1	2	3	4	5	6	n/a
	5	Lifting	0	1	2	3	4	5	6	n/a
	6	Carrying	0	1	2	3	4	5	6	n/a
SELF CARE	1	Dressing/Clasp b/h back	0	1	2	3	4	5	6	n/a
	2	Doing light housework	0	1	2	3	4	5	6	n/a
	3	Prep meals/kitchen tasks	0	1	2	3	4	5	6	n/a
	4	Bathroom activities	0	1	2	3	4	5	6	n/a
	5	Sleeping Ability	0	1	2	3	4	5	6	n/a
	6	Hygiene (comb hair/brush teeth)	0	1	2	3	4	5	6	n/a

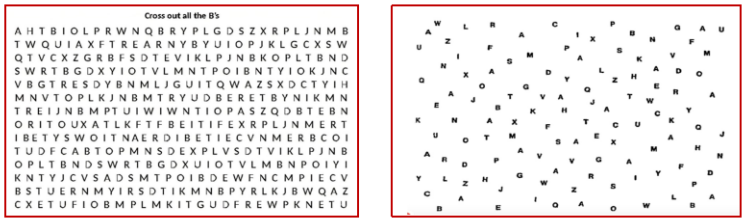
Cognitive assessments included both clinical neurological tests and a computerized neuropsychological application. The goal of these measures was to evaluate the potential cognitive rehabilitation benefits of the Torque3 platform, namely, improvement in neural conduction speed, spatial perception, cognitive flexibility, and executive functioning. The assessments for hemispatial neglect were the *Line Bisection Test* and the *Letter Cancellation Test.*

Line Bisection Test
Measure of Spatial Neglect



In this test, the subject is presented with a single horizontal line in their visual midline and asked to quickly make a mark in what they see as directly in the middle of the line, that is, to bisect it. This is done 10 times in a row and the average distance from the midline is reported as their ability to perceive both spaces equally or if they visually "neglect" of one side of their spatial perception. Marking their perception of "center" to the Right indicates a neglect (lack of awareness) of the Left space, whereas marking their perception of "center" toward the Left indicates Right spatial neglect.

Letter Cancellation Test



Subject is presented with a page full of letters in their visual midline and asked to either circle or cross out all incidences of a given letter.

To Score – the sheets are divided into quadrants and mistakes identified and counted. The Time it takes to complete the test is also recorded.

The principal assessment of perseveration was the *Luria Alternating Hand Sequences* that require one to repeatedly shift hand movements from one position to another (fist, side, flat) in the proper order. Other clinical tests included a *Random Letter Vigilance Test*, and *Visual Construction Tests*.

In addition to these clinical measures, subtle cognitive processes that are sensitive indicators of neuroplasticity required us to use a tool that could provide reliable measures of basic neural functioning and spatial perception. The riders in Phase 1 were too impaired to use certain clinical measures. Therefore, for Phase 1, we chose to use the *Defense Automated Neurocognitive Assessment (DANA)* - a tablet-based app with robust psychometric properties and reflected simple to complete tasks.

The DANA Tests included:

The *Simple Reaction Time Test* measures the speed of neural conduction and sensorimotor response. In this test, the participant must rapidly react to numerous, randomly appearing simple visual targets. The *Choice Reaction Time Test* evaluates visual identification, decision-making, behavioral inhibition, and speed.

Spatial Processing Tests measure the speed and accuracy of identifying and manipulating visual-spatial stimuli. In this test, pairs of four-bar histograms are displayed on the screen simultaneously, with one rotated 90 degrees (either clockwise or counterclockwise). The subject is required to determine whether the histograms would be identical if the rotation was not applied. A similar test called *Match to Sample* requires one to manipulate shapes mentally and identify identical patterns after a brief passage of time.

For Phase 2, the cognitive assessments were conducted via the *Montreal Cognitive Assessment or MoCA* which assesses executive functions, language, orientation, calculations, conceptual thinking, memory, visual perception, attention, and concentration. Furthermore, for Phase 2 we were able to standardize the physical therapy assessments so that comparisons were more clinically meaningful.

Virtual/Immersive Presence was assessed with the standardized *Presence Questionnaire* that measures realism, possibility to interact, quality of the interface, possibility to examine self-evaluation of performance, sounds, and haptics.

Case Reports
FAE Phase 1

The heterogeneity of members of the group makes comparisons challenging, but some trends were noted in the cohort. The results were encouraging. We present some of the individual findings in the cases below and discuss the implications.

Case 1: Bryce

Bryce is a 60-year-old male chiropractor, who experienced a massive left-sided stroke in his parietal and temporal lobes in August of 2021. This stroke occurred a week after his wife was hospitalized with complications from COVID-19 and left him with two significant deficits: one motor and one related to communication. From the motor perspective, he developed a flaccid hemiparesis of his right upper and lower extremities. His impairment was extensive.

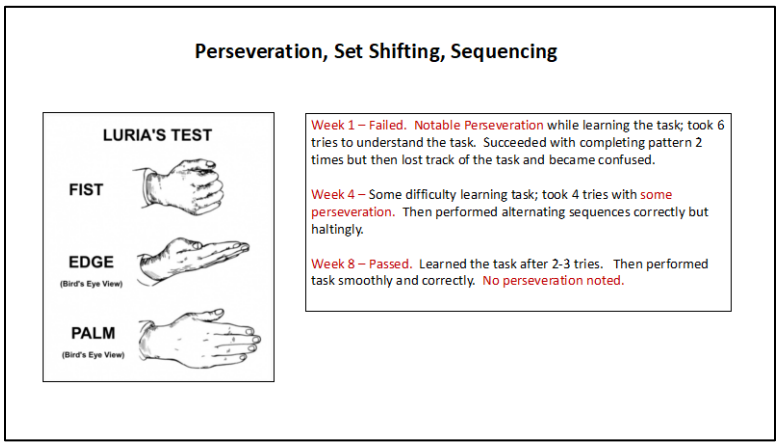
His wife, Kristi, stated that after the stroke, "*He lost full function of his right side. And his face was drooping. There was no movement in his legs or arms. He just looked completely lost. So, he had lost a lot of his former self and I'm not sure that he was completely aware of what happened to him. I don't even think he understood what had happened to him until about six weeks later when he was at his next care facility. We were ill-prepared for a major catastrophe in our lives. We had no medical insurance, we had no savings, we had nothing. So, when this went down, we just thought, Oh crap, now what?*"

Bryce's impairment had a devastating impact on his whole family and the pervasive tone in the home was one of resignation and sadness. Bryce would sit in the living room in his recliner, motionless and speechless, while the rest of the family went about their lives.

Bryce participated in extensive physical therapy and eventually showed some improvement in walking and balance. He regained some use of his right leg and was able to lift his leg and walk with the assistance of a cane. He regained some use of his right arm but was still quite motorically impaired. Bryce also demonstrated right spatial neglect. The most disabling for him was his marked impairment in expressive and receptive language, or aphasia. He was unable to spontaneously express himself beyond simple one or two words such as "yes", "no" and "what". He could repeat others' words and was reading 3rd grade level books with his wife's help; repeating words as she prompted him. His speech was slow, deliberate, and he was extremely frustrated with his inability to express himself. Kristi was told bluntly by his doctor, "*This is the best he will ever be, you need to just accept that"*.

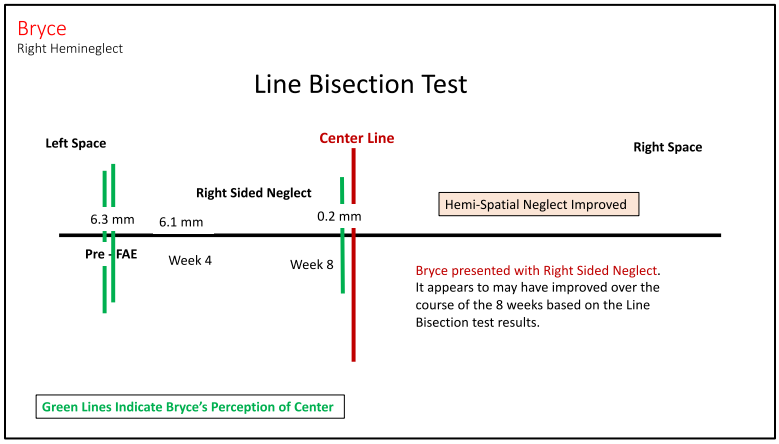
Bryce enthusiastically participated in the FAE and his results were impressive. Initially, he perseverated a great deal during motor tasks and had difficulty shifting mental and motor sets. But after the FAE, Bryce was no longer "*stuck*". Kristi stated that he was now spontaneously doing things to care for himself and was more engaged with his family. He began playing chess on his iPad and even family games like charades with very limited verbal input, but with family joyfulness. Most impressively, Kristi excitedly reported that his language had greatly improved and that the Torque3 experience had accelerated his ability to talk and express himself. He was using more words spontaneously and was much less frustrated. She stated, "*We have him back*."

Prior to the FAE, Bryce demonstrated moderate depression and mild anxiety on standard rating scales. By week 4, these symptoms were eliminated. Bryce is right-hand dominant and had to use his left hand to conduct most of the tests, which rendered many of them impossible to interpret.



However, there were some notable improvements. For example, on the *Luria Hand Sequencing Test*, Bryce initially demonstrated significant set-shifting impairment and significant perseveration, but after the 8-week FAE, that had been eliminated.

Perhaps the most impressive finding was that his hemispatial neglect was notably improved as seen in the figure below.



Physical therapy assessments also demonstrated improvement. The *Timed Up and Go (TUG) Test* showed a 20% decreased fall risk. The *BERG Balance Test* showed a 6% decreased risk of falling because of balance. The *Tinetti Gait Test* showed a 20% improved perception of balance and stability during activities of daily living, and fear of falling.

Interestingly, Bryce showed improved sensory perception. Before the FAE he was not able to feel microfilament in upper or lower dermatomes. But Post FAE he was able to feel both the microfilament and deep pressure in: C5/6, C7 and C8, L4/5 and S1 dermatomes.

Overall, Bryce had some degree of improvement in his physical, functional, psychological, and cognitive functioning. During this Phase of his FAE participation, there was no significant change on the Patient Functional Assessment Questionnaire (PFAQ). However, those changes will be reflected with ongoing use of the system as will be seen in Phase 2.

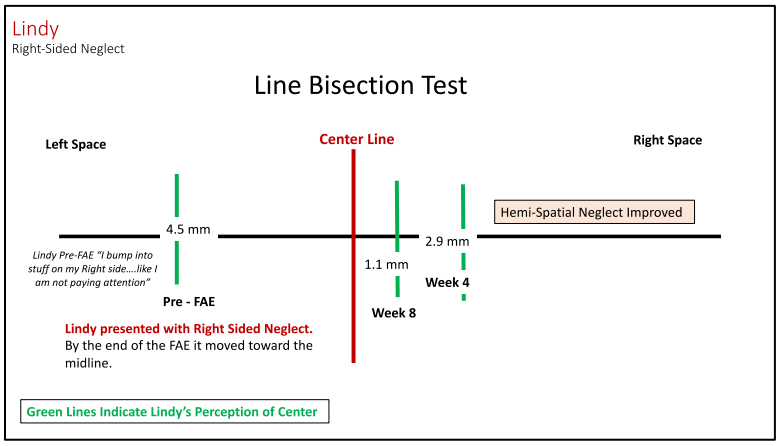
Case 2: Lindy

Lindy is a 50-year-old woman, who suddenly experienced a spontaneous hemorrhagic left-sided frontoparietal stroke in 2017. It left her with right-sided spastic hemiplegia in both upper and lower extremities as well as right-sided spatial neglect. She stated, "*My life before this stroke, I was kind of a go-getter. If it was something that seemed unachievable for a female or a small person or maybe somebody in the Latin world, I just wanted to prove that I could do it. I liked working in film, so once in a while I would take on a gig, whether it be doing the makeup for a production, doing feature work or speaking roles, or the time I was just a stand-in with one of the cast and crew characters on a Disney show. I just never thought that I would be in the position where I would have a stroke.*"

After the stroke, she had one month of inpatient rehabilitation, "*But a month wasn't long enough, and in my mind, when I was in the hospital, I was thinking I would be completely ready to go and full use of both my limbs before I left. I thought that that was the whole goal. So, I kept requesting more time. When it came time to graduate from the program - and I think insurance gave me a week longer, I can't recall, but when it was time to discharge, I was very disappointed, and I wasn't quite sure how I was going to go about getting better.*"

Persisting from 2017 until the 2023 FAE was a spastic hemiparesis and right-sided neglect, "*I keep bumping into things on my right, like I am not paying attention*" (something common for people with spatial neglect). After years of outpatient therapy, she continues to have significant lower extremity spasticity but has regained some use of her right leg. She can walk without an assisted device and drives with an adaptive driving mechanism. She continues to have significant right arm impairment and has bouts of spasticity that make normal chores quite difficult.

Lindy's results from the FAE were impressive. Her DANA assessments demonstrated 14% improvement in *Simple Reaction Time*, 17% improvement in *Choice Reaction Time*, 25% improvement in a *Memory Search Test*, and 6% improvement in a *Match to Sample Spatial Assessment Test*. Anxiety and Mood scales demonstrated the elimination of those symptoms.



Her clinical neurology findings were also striking. The *Line-Bisection Test* demonstrated improvement in her hemispatial neglect. Lindy's physical therapy assessments also demonstrated improvements. The *Timed Up and Go (TUG) Test* showed a 14% decreased risk of falling. The *BERG Balance Test* demonstrated a 5% improvement. The *Dynamic Gait Test Index* improved by 17% and her *Range of Motion* improved in both upper and lower extremities by as much as 60% in her right elbow. She stated, "*I now find myself raising my right arm to do things without even thinking about it.*" By the end of the FAE, Lindy developed a greater sense of confidence and a more hopeful outlook on life. This was reflected in a 90% improvement in the PFAQ.

Case 3: Dee Dee

Dee Dee is 57 year-old, left-handed woman who had neurosurgery and radiation treatment for a large right-sided meningioma in 2013. In 2020 she had a recurrence of the tumor and had a second surgery to resect those elements. This resulted in subsequent brain swelling and a long ICU stay, followed by 6 weeks of inpatient rehabilitation and substantial outpatient rehabilitation. She improved but continued to have frequent falls.

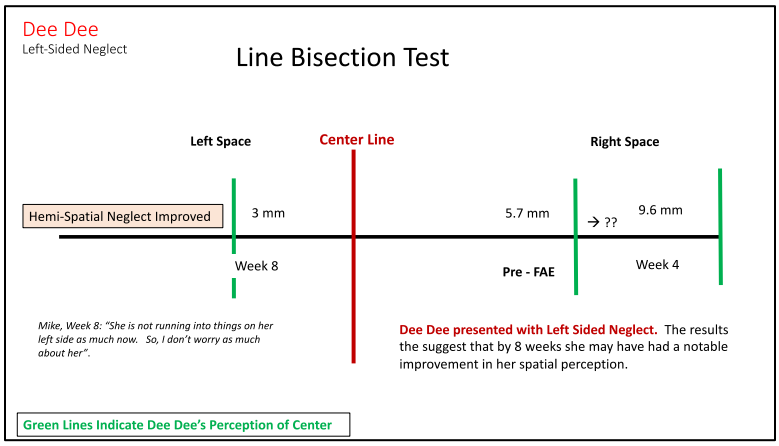
In Oct of 2022 she lost her balance, fell backward, and experienced a mild Traumatic Brain Injury that caused a major setback which resulted in the impairments seen prior to the start of the FAE. Those impairments included Left-Sided Hemiparesis affecting upper and lower extremities and an intention tremor. She used a walker and demonstrated significant Left-Sided Spatial Neglect.

Her husband, Mike, reported significant executive functioning difficulties including slow speech, cognitive slowing, and poor memory. In the pre-FAE interview, Mike looked at her and stated, "*It kind of changed your alertness level. And you came out, liking rock and roll music like you never did before. I'll tell you that much. That was one thing that really surprised me. Wow. So serious. She was like a different person. There are probably a hundred different things… hundreds of things that are hard to describe that make you - You. And now they're different. And it just happens…. even though some of them might have been hard to identify because of cognitive challenges that she had to overcome."*

Prior to her brain injury, Dee Dee worked as an employment counselor. After many years of working hard, she was able to obtain her dream job. She stated, "*I became a FEP counselor. Okay… Family Employment Counselor, where I worked with low-income families needing assistance and helping them find work and just…helping them. Losing my job…that was hard*." Losing that career after the brain injury was devastating to her.

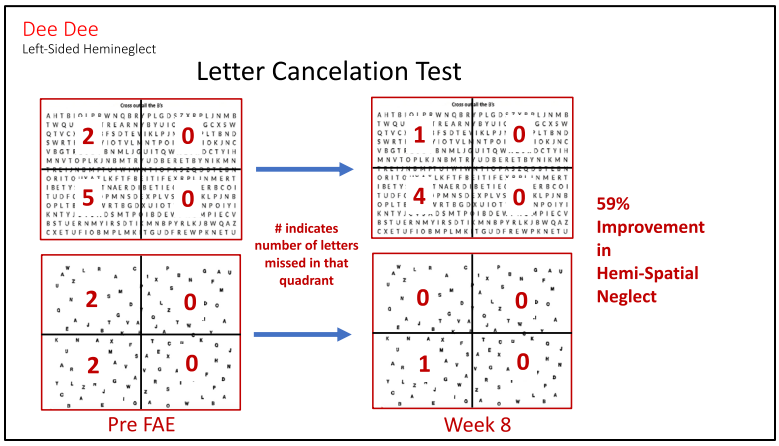
Dee Dee rode her recumbent bike for about an hour each day at home and played games with a VR headset, but neither of these showed any therapeutic benefit other than aerobic fitness. During her pre-FAE interview, Dee Dee was unable to maintain a clear historical timeline. She confused many historical and symptomatic details, and her husband had to continually redirect her and remind her of certain details. While conducting cognitive testing, she continually traced imperfections on the table and would have persisted had she not been interrupted. Her perseveration was severe.

Dee Dee was an enthusiastic participant, and she showed some marked improvements in several areas. Her DANA Tests revealed a 4.6% improvement in *Simple Reaction Time*, a 28% improvement in *Choice Reaction Time*, and a 3.8% improvement in *Spatial Processing.* Her moderate level of depression and her mild degree of anxiety were eliminated. Dee Dee showed some improvement in her hemispatial neglect as seen in her *Line-Bisection Test* (see next page).



This corresponded with observations of her performance within Torque3 Trails where she demonstrated significant improvement in orientation and navigation. She also demonstrated a 59% improvement in hemispatial neglect by the *Letter Cancellation Test*.

Dee Dee demonstrated significant motor perseveration. By the end of the FAE, this showed substantial improvement as demonstrated by several measures and observations. By observation, she no longer traced imperfections on a tabletop with her fingers in a perseverative manner and, more impressively, demonstrated a shift in perseverative behaviors while riding trails. Initially, whether on trails or during tasks, she could only pedal in a forward direction. However, with time and some coaching, she developed the ability to pedal frontward and backward, to navigate smoothly, and to avoid objects by pedaling and steering in different directions.



Dee Dee also demonstrated improvements in several physical domains. Her *Timed Up and Go (TUG) Test* showed an 8.4% lower fall risk and the *TUG Cog 2* showed a 24.9% improved speed. The *6-Minute Walk Test* showed 10.3% Improvement. The *5x Sit To Stand* showed a 50.9 % decrease which demonstrates marked improvement in balance, speed, and quad development.

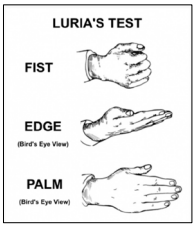
At 4 weeks into the FAE, Dee Dee stated, "*My cognition is clearer. I can say the alphabet backward and count down from 100."* By the end of the FAE she stated, "*My experience has been one of excitement and joy. Going over the waterfall was a thrilling experience, so it brought me joy.*" When asked how it felt to be in the immersive world she said, "*It felt real – so real. But I'm saying that because it was real. Because it's virtual reality, you know?"*. She expanded on her improvements by saying, "*My cognition is more alert. My body works better. Yeah, and my neighbor tells me I look better. I look healthier…. My left leg works better. So it's not as challenging as it was. I can sit and stand by myself."*

Her husband, Mike, added, "*And if I may, she does not run into things on her left nearly as frequently as she used to. Yeah, her walker makes a much smoother motion into the room, a couple of turns without hitting the doorframe or anything*." She also demonstrated her decreased tremor by holding out her non-tremulous left hand and running it over across her scalp. She even began to control her game controller with her impaired fingers and thumb. Mike also added, "*I think I've said this before - when she's talking with someone else, or with a group, her contributions are a lot more timely. They're a lot more on point, a little more wit interjected in there - both her interactions and her interactions within conversations, definitely. I noticed her alertness level increased with her interactions and conversations for sure."*

Dee Dee

Left-Sided Neglect

Perseveration, Set Shifting, Sequencing

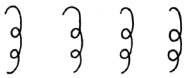


Week 1 – Marked Perseveration. Difficulty learning the rule. All fists at first , then perseverated with fists with repeated attempts. Once she learned the pattern, she continued to have difficulty shifting sets after 3 trials. She then became stuck on fists. After test stopped, she held her hand in the air in the "side" position for a few min.

Week 4 - No perseveration during performing sequences, but after the test was over, she perseverated - continued to make the sequences (incorrectly) with her right hand into her left hand rather than on the table.

Week 8 – Normal

Week 1 – Perseverated at beginning of the pattern
Week 4 – No Perseveration
Week 8 – No Perseveration



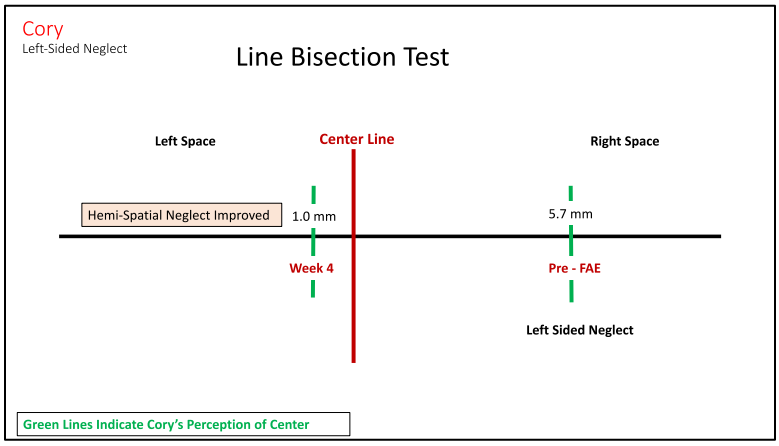
Week 1 – Minor Perseveration after the last loop
Week 4 – No Perseveration
Week 8 – No perseveration

While Dee Dee showed some exciting improvements in all areas of her life, she sadly began to have more frequent falls around week 6 of the FAE and suffered a fatal recurrence of her cancer. Prior to the recurrence of her cancer, her improved functionality as measured by the PFAQ had improved by 25%.

Case 4: Cory

Cory is a 63-year-old man who suffered a right hemorrhagic thalamic stroke on June 1st, 2022, leading to the following impairments: left upper and lower spastic hemiparesis, poor endurance, lack of motor control, decreased static and dynamic balance, left foot drop, and left shoulder pain. While rehabilitation showed some improvements, he continued to have left-sided weakness, poor dynamic balance, high fall risk, and difficulty performing desired activities such as yardwork and daily living activities. He and his wife were disappointed with the rehabilitation system that left him with continued disabilities.

Cory attended the sessions every day even though it required a 1-hour train ride each way, even weathering severe snowstorms. While his time in this FAE had to be truncated to 6 weeks due to logistical reasons, he demonstrated several improvements. His DANA Tests showed a 12% improvement in *Simple Reaction Time*, and a 5% improvement in *Choice Reaction Time.* As with our other participants, he had a marked improvement in his hemispatial neglect. Physical therapy measures showed an improvement in *Timed Up and Go (TUG)* by 30% and a 5% improvement in the *Berg Balance Test.*



Case Reports
FAE Phase 2

The heterogeneity of the Phase 2 group makes comparisons challenging, but some trends were noted in the cohort. Two of our Phase 1 participants (Bryce and Lindy) also participated in Phase 2. As with Phase 1, the results were encouraging as the cases below illustrate.

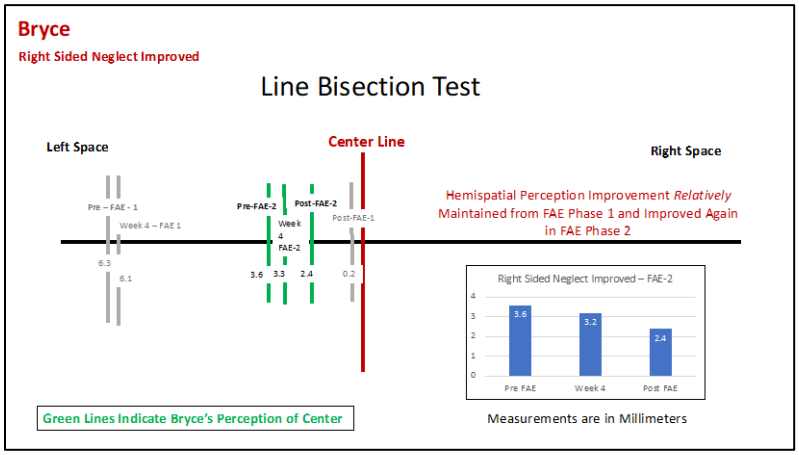
Case 1: Bryce

As stated above, Byce is a 60-year-old male chiropractor, who experienced a massive left-sided stroke in his parietal and temporal lobes in August of 2021. This stroke left him with two significant deficits: one motor and one related to communication. After Phase 1, he demonstrated improved motor function and ability to communicate as described above.

Phase 2 results: Hemispatial neglect showed a positive response. While he lost some ground in his spatial perception during the 2-month FAE gap, it remained improved compared with his pre-FAE baseline.

Bryce was unable to conduct the MoCA because of his aphasia. His aphasia continued to improve during the two-month gap between the two phases as well as after Phase 2 as described by his wife, Kristi: *"You know, he'll have a thought and then he'll start to express that. I hear him say things sometimes and think, 'What?', can I hear that again?!"* She also noted that his level of language comprehension was improving, "*When we get around people we haven't seen in a while, they are amazed at his level of understanding."*

While Bryce could not participate in our standard cognitive tools, his improvement is reflected by both his physical therapy outcomes and Family/Social outcome tools. For example, his score on the *Berg Balance Test* improved by 6% while his score on the Dynamic Gait Index improved by 21%. Both results indicate an improved ability to ambulate successfully. Phase 1 resulted in improvement of anxiety, depression, and insomnia. These improvements persisted during the 2-month gap between Phase 2 and Phase 2. His score on the *Patient Functional Assessment Questionnaire* demonstrated a 50% improvement in daily functioning.



The real-world correlation of these findings is illustrated by his wife's description of their experience on a cruise they went on at the end of FAE Phase 2. *"One of the things that I noticed is when we went on our trip, he had more energy, more stamina. Usually when we go do stuff, he gets tired and wants to go home. But on the cruise, we were off doing four-hour excursions, and he was perfectly fine. We even walked up 22 stairs to get to the top of the building to oversee a 360-degree view of the Virgin Islands. He went right up those steps. And he did that Without any kind of support, like a walker or something, he only used the banister".*

Case 2: Lindy

Lindy is a 50-year-old woman, who suddenly experienced a spontaneous hemorrhagic left-sided frontoparietal stroke in 2017. It left her with right-sided spastic hemiplegia in both upper and lower extremities as well as right-sided spatial neglect. After Phase 1, Lindy made substantial improvements in all domains. Results from Phase 2 were also impressive. In addition to her gains from Phase 1, Lindy showed additional gains on the *Lower Extremity Motor Coordination Test* (LEMCOT), the *Dynamic Gait Index* (DGI), and the *5 Times Sit to Stand Tests* (5STS). Phase 1 resulted in improvement of anxiety, depression, and insomnia. These improvements persisted during the 2-month gap between Phase 2 and Phase 2. Most remarkable was the improvement of her scores on the *Patient Functional Assessment Questionnaire* (PFAQ) which indicates her level of ADL impairment. She showed an improvement of 77%. For hemispatial neglect, she showed no significant improvements in tests in contrast to the improvements seen in Phase 1.

When asked what impact the Torque3 system has had on her, she had much to say. *"My arm's ability is way better because it used to be less and even my right leg is doing better. My walking form is doing better. I just feel like everything in totality is finally getting me back to where I was prior to the brain injury. I definitely noticed a complete improvement in my overall well-being. As far as any ailments I had prior…they are gone. I am not getting indigestion. I am not having as much trouble sleeping at night. That's always been an obstacle for me since the stroke. Everything works better with my body, even my mind. I felt like I was on a decline, just kind of dormant, not doing enough. I had therapies prior to Torque3. I feel like if I would have had the Torque3 system in my therapeutic clinic, it would have made all the difference in the world. I would have gotten better a lot quicker.*

After working with Torque3, Lindy felt she was able to reengage with her prior rehabilitation therapy. *"I feel like this system is so good no one should be without it. I'll give you an example. I was put on a brace the other day and I looked at it and thought, what is this? I didn't realize they were going to hook me up to the ceiling and with that contraption that you're on, you can walk around the gym. They were going to strap me on the brace in case I fell. It was basically a body harness and treadmill. Prior to Torque3, I probably wouldn't have wanted to do that. I probably would have found any excuse to get out of it." But after Torque3, "I feel like I was more motivated to accept any challenge coming my way. I feel like it's helped me to be more independent because I'm more of a risk taker now. I'm more able to take that risk to go in a store that I wasn't wanting to go into because it is big and there were too many people. The Torque3 simulator has helped me to overcome some of that. I feel like I'm more able to step outside of my comfort zone and put myself in a situation where I'm going to basically conform or evolve.*

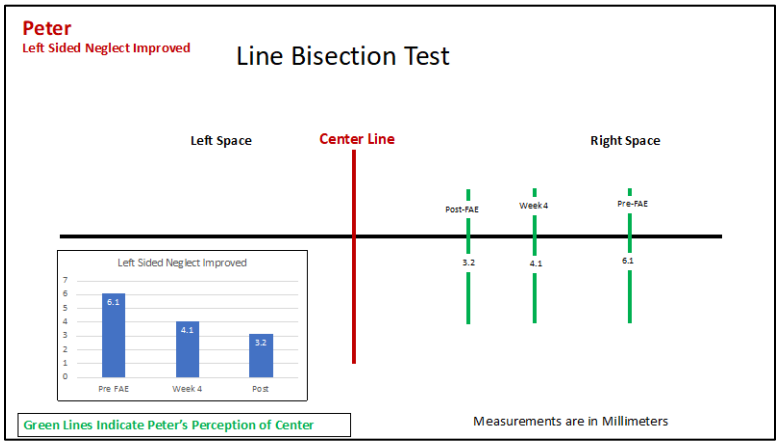
I used to be worn out the minute I got into a grocery the store. After Torque3 I can shop as long as I want. I don't have the same anxiety, I don't have the same heart issues. Before Torque3 [when shopping]*, I felt like my heart was beating really fast and I was getting kind of faint. But now I don't have any such issues at all. I would recommend to every owner or facilitator of a clinic or medical institution: If there is a possibility the Torque3 platform could be put into your clinic or center, you should seize the opportunity!"*

Case 3: Peter

He is a 61-year-old male who had an ischemic left hemisphere stroke in 2018, five years before his work with Torque3. The stroke resulted in right-sided weakness that left him with no ability to move his right foot, and weakness in his quadricep muscles and right hand. He had impaired gait and had to use a walker or cane to ambulate. Peter is a proud woodworker and carpenter and loved to work in his yard. His stroke rendered it difficult to do any of these activities. He was told that he had reached the limit of what physical therapy could provide. Peter was new to the use of our platform and his results reflect a single FAE 40-session experience.

Peter's physical therapy assessments showed significant improvement. For example, the *Berg Balance Index* showed a 21% improvement and the *Timed Up and Go Test* improved by 45%. The *Dynamic Gait index* improved by 19% and the *5 Times Sit to Stand Test* was significantly improved (he was completely unable to perform this test prior to using Torque3). Taken together, these results indicate a significant improvement in his ability to ambulate and navigate his environment. He also demonstrated a 2-point increase on the *Montreal Cognitive Assessment (MoCA).* Prior to starting the FAE, Peter showed no indication of depression or anxiety as measured by the *PHQ-9* and the *GAD-7.*

Peter initially demonstrated a substantial degree of left-sided hemispatial neglect that improved substantially over the course of the FAE. This improvement can be seen in the diagram below.



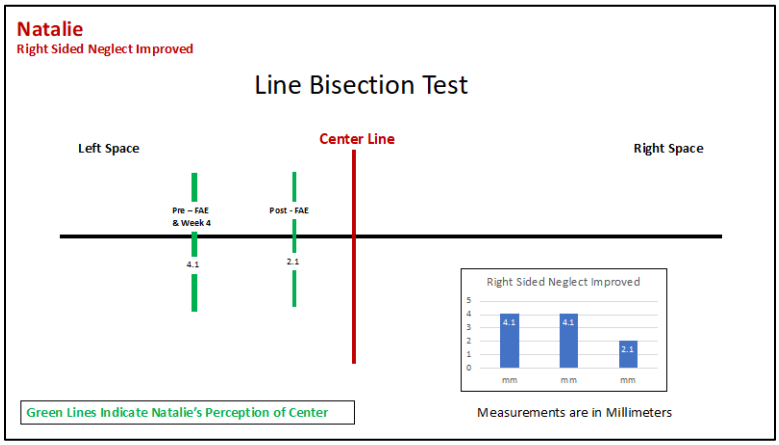
Peter was thrilled with his experience. *"Yeah, I came in with a walker and a cane and today I walk free again, without anything."* His wife said, "*Now he's able to kneel down and get back up. I found also he is braver when it comes to trying out different ways to figure something out. He does not give up. He is more adventurous or willing to try new things to figure it out."*

"I had a difficult time months ago handling tools, or carving, or sanding with the right hand. It's slowly coming back again." Recently, his wife had an injury and needed his help*, "I have relied on him to do a lot more of everything from helping me curl my hair, doing the dishes, whatever is needed. He's able to make his bed and get that done by himself every morning along with his normal morning routine."*

"We have seen improvement with his motor skills on that right hand, even his handwriting is getting better." Peter and his wife also described how he can now dig holes in the yard for 4x4 inch posts (for birdhouses he builds) again – which is bringing him joy again.

Case 4: Natalie

Natalie is a 22-year-old female who had a right hemisphere stroke in-utero that left her with Cerebral Palsy. She also experienced intractable seizures and has a resection of her right temporal lobe. This combination resulted in left-sided hemiparesis of both upper and lower extremities as well as left-sided hemineglect. Natalie had participated in several rehabilitation studies at a local university and is considered to have reached a plateau.



Her poor upper extremity coordination created significant challenges for her when performing her sessions. Making sharp turns was especially challenging. But she pushed through her frustration and her performance on the trails improved considerably over the course of the FAE. These efforts paid dividends for her as seen by her scores on various tests. Her physical therapy tests showed a 17% improvement in the *Timed Up and Go Test*. She also showed a 6% improvement in the *Dynamic Gait Index* and a 22% improvement on the *5 Times sit to Stand Test*. Natalie also showed improvement in her hemispatial neglect**.** Prior to starting the FAE, Peter showed no indication of depression or anxiety as measured by the *PHQ-9* and the *GAD-7*. She showed an impressive 92% improvement in the *Patient Functional Assessment Questionnaire***.**

At the end of the FAE, Natalie described several improvements such as a greater range of motion in her impaired shoulder making it easier to get dressed. Playing soccer with her Special Olympics group is a big part of Natalie's identity. Her ability to enjoy it has improved. *"My coach tells us to take a lap around the field. And before, my leg would like to give out because it would hurt. Because of the tightness and pain, I would just want to give up. I would just want to stop. And now I can run the whole field with my team."*

Her father added, *"Soccer practice or soccer games are typically around 90 minutes. So, it's a lot of time standing and running. She's doing a lot better in terms of staying with the group. But I think the other part of it is that she's on the field and she's actively playing and responding on the field. But another thing that's important is that she's not coming back and complaining about her leg or any pain associated with exercise, it's a significant improvement. She is remaining active and with fewer complaints about pain. It was a common thing that we would end up coming home and having to take something like Tylenol, or an anti-inflammatory. And it's rare that she takes something like that now."*

Side Effects and Presence

None of our 6 participants experiences side effects as measured by the Simulation Sickness Questionnaire and no physical adverse incidents occurred. This is unlike many, or most, virtual reality or immersive simulation systems that produce nausea, vertigo, and dizziness. The system was experienced as deeply immersive as measured by the *Presence Questionnaire* with an average presence Score = 162/168.

Conclusion:

While the number of participants is small and the findings are inconclusive, they suggest that the Torque3 platform may be able to enhance neuroplasticity and improve hemispatial neglect as hypothesized, and to do so safely. Given the very short testing period and the fact that all participants were plateaued we were totally surprised with outcomes. All participants made significant gains, some of which were life changing for both the participants themselves and their families.

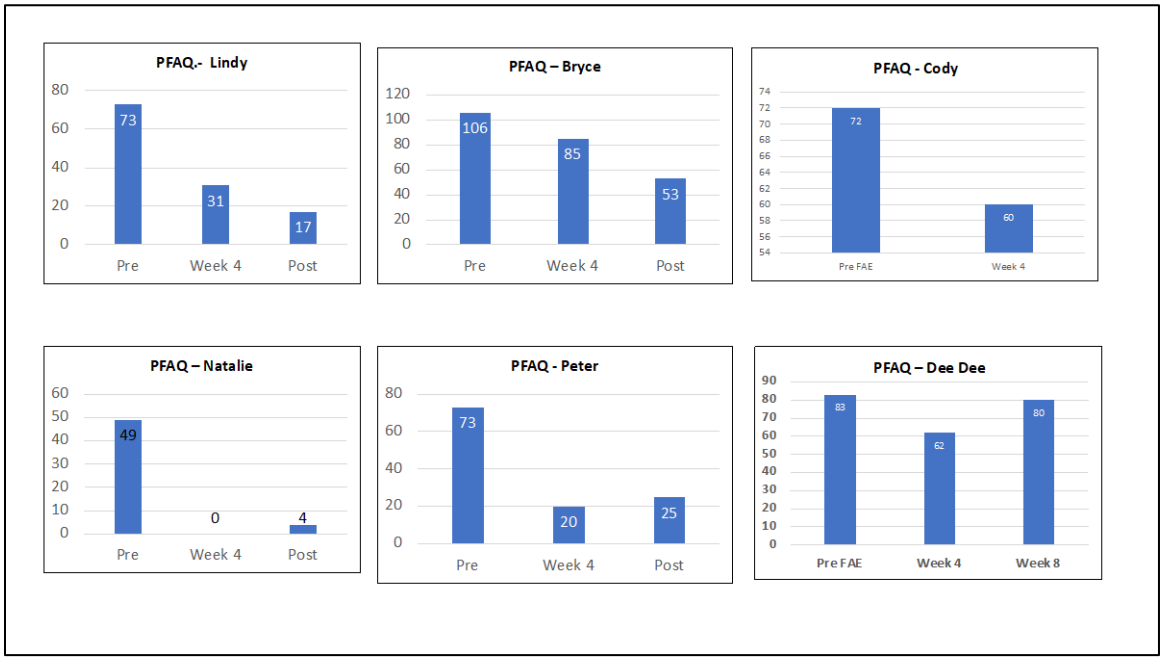
Key Measurable Findings are:

Psychological and Mental Health:

- Depression – decreased or eliminated where present.
- Anxiety – decreased or eliminated where present.

Real-World Functioning and ADL's:

Real-world functioning and Activities of Daily Living improvements in the Patient Functional Assessment Questionnaire that measures functioning in four domains including 1) Mobility / Walking, 2) Maintaining Body Position, 3) Handling/Moving Objects, and 4) Self Care.



Physical therapy assessments showed some improvements in:

- Gait
- Balance
- Postural Stability
- Fall Risk
- Lower Extremity Strength
- Sensory Perception
- Range of Motion

Physical Therapy Results - Phase 1

Test	Lindy	Bryce	Dee Dee	Cory
Timed Up and Go	24%	16%	8%	30%
Cognitive Tug	-	-	25%	-
Berg Balance	6%	5%	-	5%
Dynamic Gait Index	-	17%	-	-
Tinetti Gait Index	20%	-	-	-
6 min Walk to Stand	-	-	10%	-
5 Times Sit to Stand	-	-	73%	-
Range of Motion	Improved	-	-	-
Dermal Sensory Perception	-	Improved	-	-

Measures of Gait, Balance, and Endurance all Improved

Physical Therapy Results – FAE Phase 2

Test	Peter	Natalie	Bryce	Lindy
LEMCOTT	Improved *	Improved substantially.	Improved	Improved
BERG	22% Improved	No Change – high initial score	6% Improved	Not improved, times varied based on fatigue level.
TUG	45% Improved	17% Improved	Not improved, times varied based on fatigue level	Not improved, times varied based on fatigue level.
DGI	19% Improved	6% Improved	21% Improved	3% Improved
5 STS	Improved substantially! Unable to complete test Pre FAE!	22% Improved	Not improved, times varied based on fatigue level	7% Improved

Berg Balance Scale (Berg) → Higher = Better
Timed Up and Go test (TUG) → Lower = Faster/Better
Dynamic Gait Index (DGI) → Higher = Better
Five Times Sit to Stand Test (5STS) → Lower = Faster/Better

Measures of Gait, Balance, and Endurance Improved
* Test not completed on affected side

Cognitive findings revealed improvements in:

- Speed of neural reaction (DANA)
  - Simple Reaction Time (4-36 ms)
  - Choice Reaction Time (18-27%)
- Perseveration
- Spatial Perception (DANA, 4-5%)
- Hemispatial Neglect – Marked improvements for each participant.