BIONIK
InMotion® Robotics

Using IoT Data to Quantify InMotion® Therapy Gains on Upper Extremity Motor Impairments

ABSTRACT

The InMotion® Robotic Systems, by BIONIK have been tested by leading medical centers in more than 150 independent controlled clinical trials, including large randomized, double-blind, peer-reviewed clinical studies involving more than 1700 patients. BIONIK is targeting stroke recovery and rehabilitation worldwide through its connected software and robotics technology. This report details the clinical effects of InMotion Therapy on patient recovery and related trends in the US from 2019 through 2021. Notably, patients who had 3 or more InMotion therapy sessions experienced significantly greater median improvement rates compared to those who only had 2 sessions in the same timeframe. For a 14-day timeframe, improvement rates in the kinematic and kinetic measures improved 8% to 20%. This presents strong evidence that increasing the number of InMotion robot-assisted therapy sessions is associated with greater therapeutic gains for patients suffering from upper-extremity motor impairments.

INTRODUCTION

More than 15 million strokes occur each year around the world, and 30% of survivors are left permanently disabled. In 2016, the worldwide stroke prevalence was 80 million[5], and with an aging population worldwide, the prevalence of stroke is likely to increase. BIONIK is a global healthcare company aiming to transform neurorehabilitation by helping patients reclaim their mobility through cloud-connected, robotic-evaluation and therapy. The company's line of robotic rehabilitation devices are the result of research and development from the Massachusetts Institute of Technology (MIT). BIONIK's technology offers the rehabilitation clinician powerful robotic assisted tools to help drive positive patient outcomes. There are currently more than 280 InMotion robotic systems in use worldwide.

DATA COLLECTION

Starting in 2019, newly installed InMotion robotic systems were equipped with InMotion® Connect Pulse, making InMotion the first rehabilitation robotics system to be utilized as an Internet of Things (IoT) device. InMotion Connect Pulse enables administrators and managers to securely track therapist engagement with InMotion Robots, ensuring optimum utilization in one facility or across an entire health system. All data reported by the Pulse system is anonymized at the source to ensure patient privacy. The data for this report was collected through InMotion Connect Pulse from multiple healthcare facilities during the reporting period.

WHAT IS InMotion?

BIONIK's InMotion Robotic Systems are the result of years of collaboration between engineers, medical professionals, clinicians, technicians, and patients. The InMotion ARM (shown in Figure 1) and InMotion ARM/HAND are rehabilitative robots intended for the evaluation and treatment of patients with upper-extremity motor impairments following a neurological condition or injury. This includes rehabilitation after Stroke, Cerebral Palsy, Spinal Cord Injury and other movement disorders (although the devices can also be used in psychophysical, movement control, and movement disorder research).

The Robotic Systems facilitate interactive therapy tasks intended to restore upper extremity motor control and provide evaluation assessments to objectively measure and report the patient's upper-extremity motor impairment and progress during therapy. Impairments to the shoulder, elbow and hand movement may be treated on either the left or right side. Studies have demonstrated that InMotion Robotic Systems are beneficial in the treatment of pediatric and adult patients during the acute, sub-acute and chronic stages of neurological recovery[1],[2].

Fig 1: InMotion ARM Robotic Rehabilitation System

In the neurologic rehabilitation process for the upper extremity, the process of returning to functional use of the arm requires changes in the brain structure to accommodate for loss of brain function caused by the original neurologic insult. This process, called neuroplasticity, requires repetitive movement of at least 10,000 repetitions to achieve the goal. Rehabilitation specialists have been asking how to achieve this goal for years, and rehabilitation robotics may have the answer. InMotion's Robotic Systems enhance the therapist's ability to drive repetition and neuroplasticity compared to traditional therapy.

The basis of that rehabilitation is an increase in the number of repetitions achieved. Whereas a one-hour traditional therapy session typically achieves between 35 and 60 repetitions[3], the same 1-hour session using the InMotion Robotic System can achieve over 1,000 repetitions[4]. The device is adaptive, tailoring its assistance to the patient's ability and continually adjusting as the patient improves. Video-based therapeutic activities create a fun and engaging environment beneficial to recovery. Positive reinforcement and sensorimotor feedback accelerate the rehabilitation process.

InMotion THERAPY GROWTH TRENDS

InMotion has been used to help thousands of patients since its inception. As of January 2022, InMotion Robotic therapy has helped 6,129 patients across 26 clinics (figure 2a). The number of monthly patients using InMotion therapy has steadily increased from early 2019 to late 2021. While patient growth slowed during the peak period of the COVID-19 pandemic, the number of monthly patients has increased once again. These 26 clinics equipped with InMotion Connect Pulse, now provide recovery therapy for more than 250 patients in a typical month.

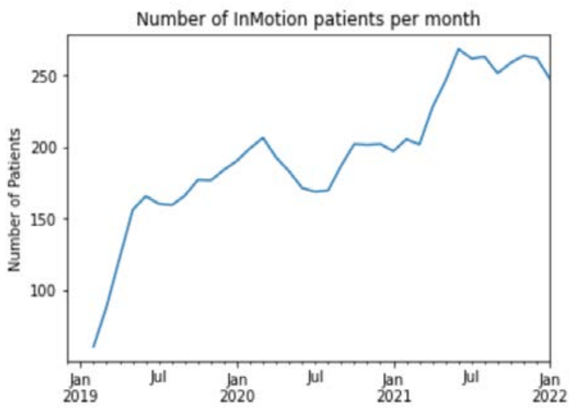


Figure 2a: 2019, sites using InMotion

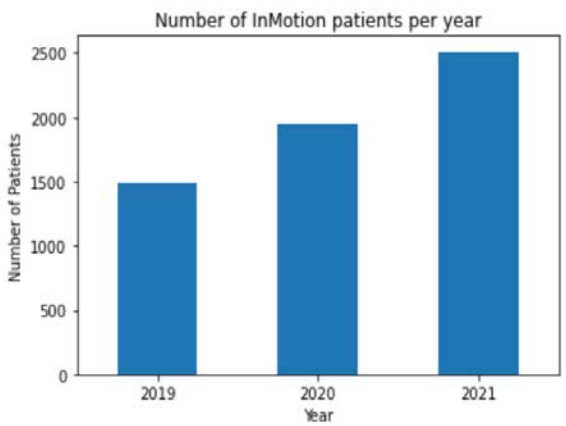


Figure 2b: 2021, sites using InMotion

The number of monthly therapy sessions have increased by 45% from 2019 to 2021, from 3869 to 5625. As seen in Figure 2b, over the same time span, the number of sites conducting InMotion robotic therapy has increased more than three-fold, from 8 clinics in January 2019 to 26 clinics in December 2021. As seen in Figure 3a and b, the geographic reach of conducting InMotion robotic therapy has expanded from a concentration in the Southwest in January 2019 to most of the country by December 2021.

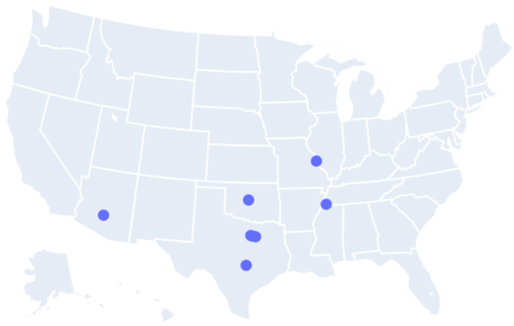


Figure 3a: 2019, sites using InMotion

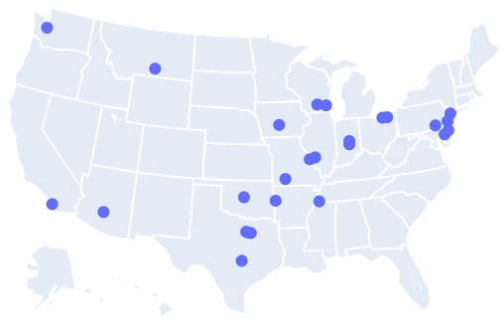


Figure 3b: 2021, sites using InMotion

HOW DOES InMotion FIT INTO A TYPICAL THERAPY SESSION?

A clinician's use of the InMotion Robotic System can take many forms. Some use robot-assisted therapy for an entire patient session, while others combine it with more traditional techniques. Clinicians typically run a set of evaluation activities to measure a patient's current kinetic and kinematic impairment in the upper extremities, move onto therapy activities designed to stimulate neuroplasticity for arm and shoulder movements, and lastly run a second set of evaluation activities to compare the patient's starting metrics to their ending metrics. The typical time with the Robotic System ranges between 20-60 minutes.

> *"One of the things the robotic arm does is it gives the patient repetition… We're able, with the [InMotion] arm, to allow them to get 100, 300, 400 movements in one session, without them being overly fatigued and of course the therapists being overly fatigued."*

The most frequently used InMotion therapy activities include point-to-point movements, stabilization, resistance, and two modes that are based upon principles of motor learning to increase the pace of recovery. The clinical motivation for each activity is listed in Table 1:

Table 1: Clinical motivation for therapy activities

Therapy Activity	Description	Clinical Motivation
Point-to-point movement	The patient moves the end-effector in straight lines, from the center of a circle to each of the 8 targets positioned around the edge of the circle.	Facilitates the development of smooth and controlled movements, aligned with motor planning.
Stabilization	The patient holds the end effector on the center target while the robot attempts to move the patient's arm/robot handle toward the outer edge of the circle.	Stabilization activities are isometric hold tasks intended to promote shoulder and elbow muscle co-contraction.
Resistance	The patient moves against increasing resistance force as they reach toward the outer targets for one rotation around the circle. The robot will attempt to hold the arm handle in the center location.	Robotic resistance therapy is intended to facilitate general muscle strengthening.
Error Augmentation	The patient moves the end effector in straight lines, from the center of a circle to each of the 8 targets positioned around the edge of the circle. The device then visually magnifies movement errors by a factor of 2x, 3x, or 4x.	These activities are designed to assist with fine tuning motor control and refining smoothness and path deviation errors. Error Augmentation is a good option for patients with motor, visual, and/or attention impairments.
Curl Perturbation	The patient moves the end effector in straight lines, from the center of a circle to each of the 8 targets positioned around the edge of the circle. A perturbation force, proportional to the velocity of movement by 12 or 24 Ns/m, is applied perpendicular to the direction of movement that the patient needs to overcome to reach the target.	These activities help patients who need to improve their ability to adapt to changes in the environment as well as requiring them to hold a position in space consistently. No robotic assistance or performance metrics are provided during Curl Perturbation activities.

In addition to these core therapeutic activities, clinicians have been increasingly using the InMotion Robotic System's additional activities to add a more cognitive focus while continuing to reinforce movements that improve range of motion and eye-hand coordination.

The Squeegee activity, for example, is based on a window-washing metaphor. Different background images may be selected, and the aim of the task is to reveal the image space by moving the squeegee pointer across the entirety of the screen. The activity involves high repetitions of both straight line and therapist-directed patterns of movement, as well as the active coordination of a patient's range of motion with on-screen effects. Because the activity also requires visual scanning of the image space, it is an activity that can be used to assess visual neglect and cognitive deficits in patients, differentiating it from motor impairments. It has been the most widely used of the additional activities and clinicians consistently cite it as being extremely valuable to everyday patient therapy.

"[InMotion] has increased engagement and participation in patients that I have had difficulty completing therapy within the past."

InMotion Robotic Systems also include a Maze activity, a Paddle-ball activity, and an Obstacle avoidance activity — each of these are therapeutic for patients with visual field, spatial awareness, coordination, delayed responses, attention and/or motor control deficits. Clinicians choose additional activities based on desired therapy focus areas or based on patient preference. By finding ways to tailor a therapy session not only to a patient's needs, but also their preferences and interests, we can hold patient focus for longer and encourage more repetitions.

"[My patient] demonstrated increased engagement during InMotion activities than with other therapy tasks."
"It's a great Active Assisted Range of Motion or Passive Range of Motion program, fun and interactive for the patient, takes their mind off of the deficit."

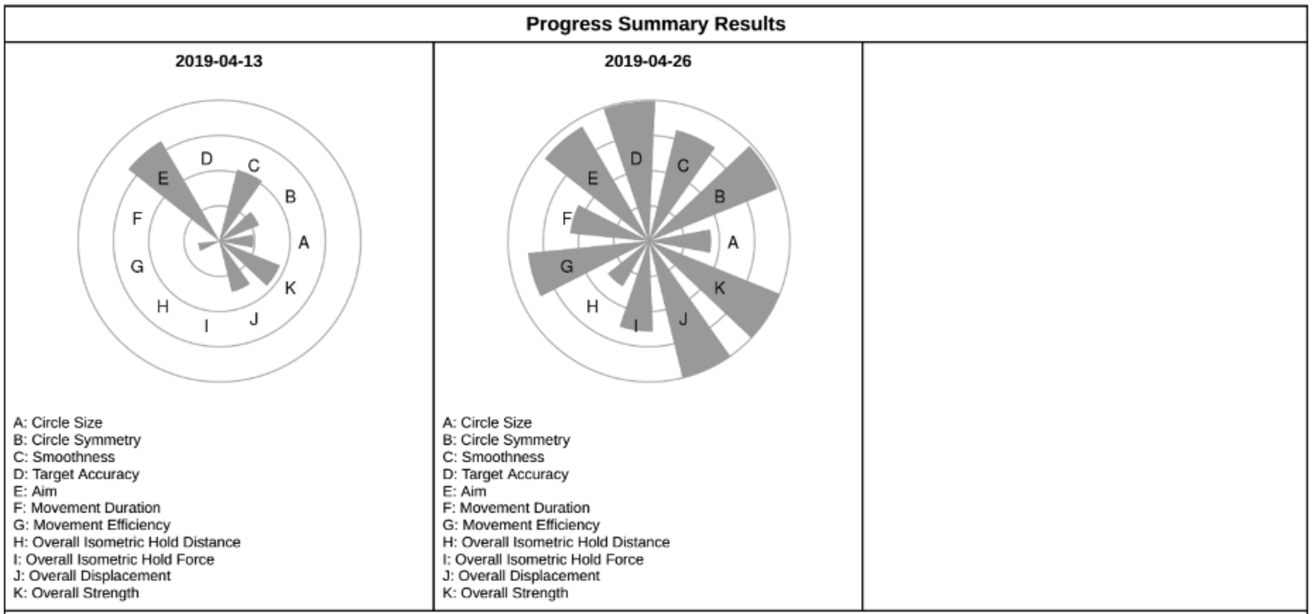
The flexibility of the InMotion therapy activities is evident in the breadth of patients that have used it. While much of the research initially involved stroke recovery therapy, clinicians have been using InMotion across a wide range of conditions including spinal cord injury, traumatic brain injury, ataxia, cerebral palsy, multiple sclerosis, Guillain-Barré syndrome, visual perception issues, as well as both acute and chronic inflammatory demyelinating polyneuropathy. InMotion therapy is actively being used across all age groups, from pediatric (developmental age 4 and up) to the elderly.

“A patient with an incomplete central cord [spinal cord injury] was evaluated on the robot. Prior to evaluation she had been very discouraged by her limited upper extremity function, almost feeling as though she couldn’t do anything with them. After evaluation she was so encouraged that she actually was able to do a lot with them and had a good baseline to start addressing and strengthening.”

InMotion Therapy IMPROVES PATIENT OUTCOMES

InMotion Robotic Systems collect kinematic data during patient therapy sessions. They continuously measure the position, velocity, and forces of the shoulder and elbow — raw measurements from which its software calculates metrics that capture the smoothness, speed, and degree of control in the patient’s movement. The metrics are tracked over time, session-by-session and activity-by-activity, providing patients with real-time reports (shown in Figure 4) detailing their progress. InMotion’s data visibility has proven to be a big motivator for patients and provides valuable insights for clinicians.

"There’s nothing like a patient being able to see progress on a piece of paper. And looking at that screen and seeing where they were and where they are. It proves their progress. And so the biofeedback is an incredible positive component of the robotic arm system."
“I had a patient who was really excited by his progress on the star after we re-evaluated and we hung his first and second eval side by side in his room so that he could show them off.”



Summary Plots: Improvement in each of the robotic measures can be tracked with the summary rose plots of % EP. Although some measures may get smaller while other measures improve as part of the rehabilitation process, as shown in clinical studies, an overall expanding or larger rose plot indicates that the arm is improving over time.

Figure 4: Example of a patient progress report for the InMotion ARM Robotic System

By analyzing these metrics, we can begin to directly quantify the effectiveness of InMotion robot-assisted therapy. Clinical research has already established that robot-assisted therapy helps improve stroke recovery[1],[2]. But InMotion's detailed datasets also reveal the therapeutic impact of increasing the number of robot-assisted therapy sessions.

WHAT IS THE IMPACT OF INCREASING THE NUMBER OF ROBOT-ASSISTED THERAPY SESSIONS?

Our analysis looked at improvement metrics calculated for patients having 2 sessions compared to those having 3+ sessions, over the same time period. Because stroke victims experience some degree of natural recovery as time passes from the event, it was important that we only compare samples of patients whose time with the InMotion Robotic System spanned similar ranges. We focused our analysis on the point-to-point therapy activity, as this activity had the greatest sample sizes across all metrics and time frames. Metric values from the patient's first session were compared with metric values from the patient's final session, and the percentage difference was calculated as a measure of general improvement. We then compared the median improvement rate for patients who had 2 sessions to the median improvement rate for patients who had 3+ sessions in the timeframe and considered this difference in rates to be an indicator of the impact of adding additional therapy sessions.

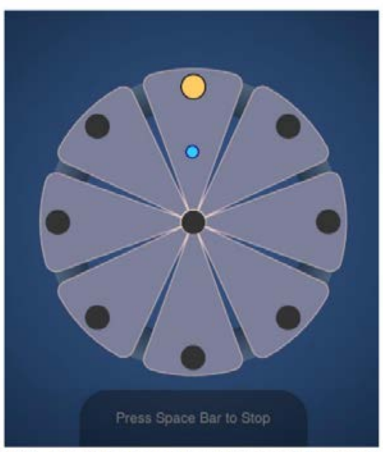


Figure 5a: The point-to-point assessment's on-screen display

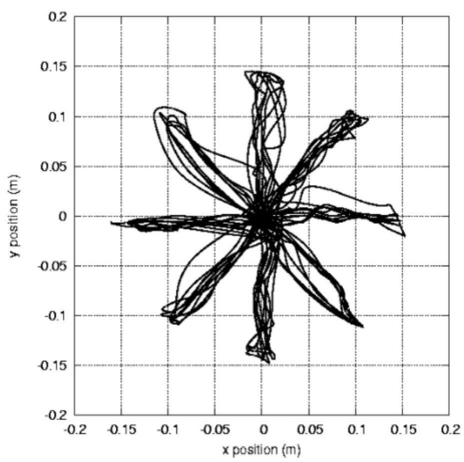


Figure 5b: An example of point-to-point assessment patient results

There are nine available metrics for the point-to-point therapy activity, listed in Table 2.

Table 2: Available metrics for point-to-point therapy activity

Metric Name	Definition
Smoothness	A measure of the smoothness of arm movement. It is calculated as the ratio between the average speed and the peak speed. A larger value indicates an increased ability to control changes in speed. Smoothness is important for tasks such as independent feeding and cooking, (e.g., moving a spoon from bowl to mouth or drinking from a cup).
Movement Duration	The average time taken to move toward the outer targets. A smaller value indicates greater functional speed of reaching movement. Movement Duration is important for reaction time to a danger during performance of ADL's.
Movement Efficiency	The ratio of the total distance of the patient's movement path with respect to the straight-line distance between the targets. A smaller value indicates a greater ability to directly move between two points.
Initiation Time	The average time taken for a patient to initiate movement in response to a new target. This may represent a patient's motor delay. A smaller value indicates improving motor response.
Mean Velocity	The mean velocity of a patient's movement from target to target.
Max Velocity	The maximum velocity, measured by the robot, as the patient moves the pointer from target to target.
Aim	The average deviation from the straight-line path during arm movement. A smaller value indicates more controlled, purposeful and direct movement. Straight-line accuracy is important during tasks such as cooking on a stove top, reaching for a glass in a cupboard or mobilizing with a walker or wheelchair.
Target Accuracy	The proximity to the outer targets reached by arm movements. A smaller value indicates a greater range of arm movement with more accuracy. This measure is relevant to functional tasks, such as reaching for a glass or bottle, putting on eyeglasses or reaching for a door handle.

Table 3 highlights the therapy results for patients in a 14-day time window, as this represents the duration of a typical in-patient stay:

Table 3: Median %-improvement between first and last session (14-day timespan)

Metric	Patients having had 2 sessions	Patients having had 3+ sessions	Difference between patient groups
Smoothness	4.2%	19.3%	+15.1%
Movement Duration	15.6%	23.5%	+7.9%
Movement Efficiency	4.2%	21.2%	+17.0%
Initiation Time	5.2%	37.3%	+32.1%
Mean Velocity	18.1%	30.8%	+19.7%
Max Velocity	8.0%	16.5%	+8.5%
Aim	9.1%	30.9%	+21.8%
Target Accuracy	8.8%	19.6%	+10.8%

We find that for all metrics, patients who had 3+ sessions in a 14-day timespan improved by at least 8 percentage points more than patients who had only 2 sessions, and for some metrics this difference was more than 20 percentage points. (The metrics in black are ones where this holds true regardless of the timeframe analyzed, whereas metrics in gray would sometimes show greater improvement for 2-session patients, depending on the time frame.)

Expanding our analysis across all possible time frames, we see that overall, median improvement rates are significantly higher for many-session patients than for 2-session patients (Wilcoxon signed-rank test, n=128, p < 5x10-9). This statistical test asks, “what are the chances that we would observe patient outcome data like this if there were no true difference between the 2 patient groups?”, or put more succinctly “what are the chances that we’re seeing results like this due to chance?” With a p-value so low, 5x10-9, the test tells us that this chance is nearly 0. The visualization in Figure 6 shows the distribution of all median improvement rate differences for point-to-point therapy activities, across all timeframes and all metrics. We see that for nearly every data point in the histogram, the differences are positive, meaning that many-session patients typically see greater improvements than 2-session patients.

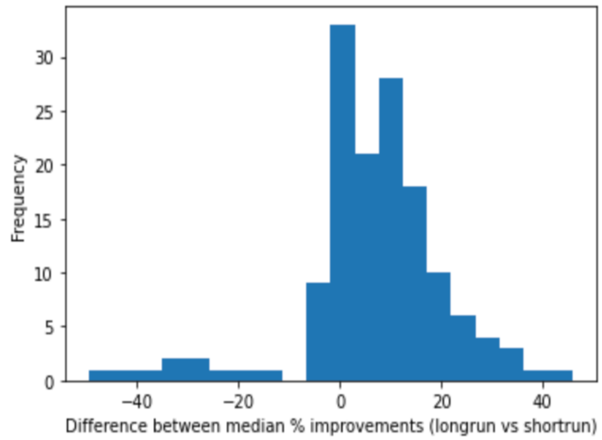


Figure 6: Distribution of difference between median improvement rates of many-session patients and 2-session patients, across all metrics and all timeframes analyzed.

The consistent improvement in these metrics suggest that continuing to pursue additional robot-assisted therapy sessions improves a patient's ability to move smoothly, with intention, in a controlled manner. Combined with the previous clinical results cited earlier, we see that not only does robot-assisted therapy improve stroke recovery compared to control groups receiving usual care, but that increasing the number of robot-assisted therapy sessions is associated with increased recovery patterns.

"I used InMotion 3 times in 1 week on a fairly motivated stroke patient. By end of week, we were able to increase engagement, improve postural stability, improve Active Assisted Range of Motion, and increase resistance."

"A young, active patient who had a cerebrovascular accident and no noted movement in upper extremities was able to see his arm move on the InMotion. Seeing this movement was uplifting and motivating. He continued to use InMotion about 2x/week (would have loved to daily but couldn't dedicate every session to InMotion) and saw clear improvements. He was discharged home, returned to outpatient therapy and continues to use the InMotion to regain upper extremity active range of motion."

CONCLUSIONS

Patients who had 3 or more InMotion therapy sessions experienced significantly greater median improvement rates compared to those who only had 2 sessions in the same timeframe. For a 14-day timeframe, improvement rates in the mean velocity of patient arm movements were 20% higher; improvement rates in the aim, smoothness, efficiency, and motion jerk of the movement were 15-20% higher; and improvement rates in the average time taken to move from target to target were 8% higher. This presents strong evidence that increasing the number of InMotion robot-assisted therapy sessions is associated with greater therapeutic gains for patients suffering from upper-extremity motor impairments.

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[1] Lo. A.C., et.al "Robot-Assisted Therapy for Long-Term Upper Limb Impairment after Stroke," New England Journal of Medicine, 362:1772, May 13, 2010.

[2] Volpe, B.T., Krebs, H.I., Hogan, N., Edelstein, O.L., Diels, C. and Aisen, M. "A novel approach to stroke rehabilitation: Robot-aided sensorimotor stimulation," Neurology, 54 (2000) 1938-44.

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[5]Vasu Saini, Luis Guada, Dileep R. Yavagal "Global Epidemiology of Stroke and Access to Acute Ischemic Stroke Interventions." Neurology Nov 2021, 97 (20 Supplement 2) S6-S16; DOI:10.1212/WNL.0000000000012781