HYBRID ASSISTIVE LIMB AND ITS APPLICATIONS IN PHYSICAL REHABILITATION

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Abstract—Walking is a daily task that is often taken for granted, but for some people this simple task is considered a challenge, or even an impossibility, due to factors such as old age, genetic disorders, or unexpected medical accidents. With the support of an exoskeleton, those with physical impairments can regain the ability of voluntary muscle movement. Hybrid Assistive Limb (HAL) is a robotic exoskeleton suit that strengthens and reinforces the wearer’s body movements. HAL has the ability to receive bio-electric signals sent from the brain to the muscles using a device that reads electromyogram (EMG) signals to instruct the exoskeleton how to move [1, 2]. This movement is controlled through force sensors which drive the assist method based on phase sequencing [3].

Since the product launch in 1992, HAL has constantly been improved in areas such as weight reduction, mobility, and autonomy [4]. The most current model of HAL will be discussed in this paper. A detailed description of the exoskeleton’s process controls will be included as well as applications and case studies [5]. Lastly, information on the ethical issues of standardization, user injury, and cost will be discussed [6]. Throughout the paper, aspects of HAL’s sustainability will be explained with respect to quality of life and price.

Key words—autonomy, bio-electric signals, HAL, phase sequencing, rehabilitation, robotic exoskeleton

OVERVIEW

Movement is crucial for most daily activities and independence. Although, people often move without even thinking, for some this innate ability cannot be achieved. This incapability is often due to either an imbalance of chemicals in the brain or physiological damage as a result of injury or the aging process. Current rehabilitation options are limited and often inadequate in reestablishing voluntary movement for these patients. Hybrid Assistive Limb (HAL) is a robotic exoskeleton that allows immobile individuals to obtain control over their movement.

A description of possible issues that result in difficulty of movement will be presented in order to establish an understanding of the issue at hand. Following this, current rehabilitation options and their disadvantages will be described. A solution to these insufficient treatment options is a robotic exoskeleton that reinforces the user’s desired body movements. This paper will focus specifically on HAL and its main components. The effectiveness of this device will be illustrated through the use of case studies involving patients affected by Hemiplegia and poliovirus. Finally, the ethical concerns surrounding HAL will be discussed. Sustainability is an important aspect of all technologies; therefore HAL, in terms of sustainability, will be integrated throughout the paper.

SUSTAINABILITY

Sustainability has a broad definition. As defined by the United Nations World Commission on Environment and Development, sustainability is “satisfying the needs of the present generation without compromising the ability of future generations to meet their own needs” [1]. To many people, this refers to reducing one’s environmental footprint. Sustainability, however, also involves social and economic aspects. One of the most important social aspects is improving the quality of a person’s life. In the case of HAL, improving quality of life is achieved through regaining mobility, which lessens the amount of obstacles one must face with immobility, such as constantly needing to rely on others for their own movement. Therefore, HAL makes daily life easier and overall more enjoyable for the user. In respect to economic sustainability, products that require significant funds to produce and, as a result are expensive for consumers to acquire, are not considered sustainable. This is because, no matter how beneficial a product is, it is of no use if it is unattainable due to an unreasonable cost. Unfortunately, at this time, improvements need to be made in order for HAL to become economically sustainable. A more detailed discussion of sustainability in relation to HAL will be included in later sections.

ISSUES WITH MOVEMENT

Human movement is extremely complicated and involves several different processes. The musculoskeletal system of the human body, which consists of the skeletal muscles that are attached to the bones, is ultimately responsible for producing this movement [7]. The skeletal muscles responsible for movement are formed by muscle fibers, which are further divided into bundles of myofibrils [8]. In order for movement to occur, these muscle fibers must receive a signal telling them when and how to move. The signals that generate movement originate in the brain. The part of the brain that is primarily responsible for transmitting motor commands is a part of the cerebral cortex known as primary motor cortex (M1). In addition, the cerebellum is important for the regulation of size and direction of movement, and the basal ganglia is needed to make changes in voluntary movement by
controlling conflicting patterns through reinforcement or suppression. Once the signals are established in the brain, they are sent down through the spinal cord to motor neurons which relay the signals to the muscle [8]. It is clear that voluntary movement is very complex and a number of things can go wrong resulting in a lack of motor skills.

Disorders of the central nervous system, which consists of the brain and spinal cord, are major causes of a lower limb disability [9]. Depending on the location of the lesion, which may be a result of disease or trauma, neural pathways can be obstructed and the lower part of the body may lose its function. If the injury is located in the cerebellum, for example, issues in executing voluntary movements will arise such as difficulty with coordination, and a range of motions. On the other hand, disorders that diminish movement, such as Parkinson’s disease, or cause an excess of movement, such as Huntington’s disease, result from problems of the basal ganglia [8]. In addition to lesions in specific parts of the brain, general damage to motor neurons or the muscle itself can cause muscular atrophy. Lastly, a person’s bones, joints, heart, lungs, metabolic system, peripheral nerves, central nerves, and other major body systems must be functioning properly in order to achieve smooth movement [7]. With countless reasons for immobility, it is clear that this issue has the potential to affect a large number of people. Therefore, an optimal and sustainable solution is needed; this solution is HAL.

REHABILITATION OPTIONS

People with mobility impairments generally have few treatments options available to them. Most patients are treated using exercise. In rehabilitative exercise, the impaired movement is generally trained with a resistance that is similar to that experienced in daily life. By training with this type of resistance, muscle strength will increase and allow for improvement of life functions. However, this option requires a certain speed of movement and range of joint motion to be effective. Those suffering from issues involving the central nervous system are unable to perform these tasks and instead must repetitively perform activities for improvement. In general, the idea is that by performing repetitive movements an external rhythm is acquired. Another option for rehabilitation is using external stimuli to generate reactions of the musculoskeletal system, such as electric stimulation or restriction of blood flow in order to increase muscle strength and volume. Despite being the most currently used methods, exercise and use of external stimuli are not very effective. Few therapeutic approaches have shown to significantly improve motion for patients with central nervous system disorders. Additionally, to achieve any form of relief, these methods must be performed over long periods of time, which comes at a high cost [7]. To give some perspective on just how much this can amount to, the average cost of an accident resulting in paraplegia in a 25 year old amounts to approximately $2,250,000 over their lifetime [12]. This price of course varies with the severity of the incident, and the age at which the incident takes place. Such a high cost shows that current rehabilitation options are not sustainable. A robotic exoskeleton, on the other hand, has the potential of being an effective rehabilitation device for these patients because it can replace body functions and carry out the motions of a physically healthy person [3]. Therefore, robotic exoskeletons replace the need for long-term rehabilitation by simply wearing the device. This allows for continuous payments over a person’s lifetime, which would add up significantly, to be reduced to one payment. In order to successfully replace current rehabilitation, a robotic exoskeleton must be developed that is both economically sustainable and effective at producing mobility.

ROBOTIC EXOSKELETONS

Robots made for rehabilitation began in North America in the 1960’s and were used as teleoperation robots, meaning that they can be controlled from a distance. The control and sensing methods were not adequate, however, resulting in issues involving safety. The first full body exoskeleton was also created in the U.S. in the 1960’s for the purpose of heavy load lifting in order to aid soldiers, as well as lessen the strength required to lift patients in health care facilities [5]. Since then, improvements have been made and robotic exoskeletons are now being applied as rehabilitation devices for people with physical impairments.

HYBRID ASSISTIVE LIMB

A current example of a robotic exoskeleton is the Hybrid Assistive Limb (HAL), which is depicted in Figure 1. With HAL, a human’s physical abilities are enhanced and supported [5]. The robotic exoskeleton is able to move the way the user intends by receiving and interpreting electromyogram (EMG) signals [2]. HAL consists of an exoskeleton, power units, sensing system, interface units and a main controller [5]. The exoskeleton is a frame that consists of three-link mechanism that corresponds to the hip, thigh and lower thigh, and a two-joint mechanism that corresponds to the hip and the knee joints [3]. The exoskeleton can be seen in Figure 1 as the white structure. The power units of HAL generate the torque required to move the exoskeleton in the desired motion. The power units are made up of a motor driver, microprocessor, communication interface and an actuator. The torques of these power units are applied to the user’s leg through the frame of the exoskeleton [5]. The sensors of HAL consist of rotary encoders that measure the hip and knee joint angles; floor reaction force sensors that are used to control autonomous motion; and myoelectric sensors that are attached to skin to detect muscle activity [3]. The interface units are used to alter HAL’s parameters and batteries. It consists of a power switch and voltage dividers, known as digital potentiometers, which allow for control of
the circuits and modification of the amount of assistive torque applied. This gives the user the ability to turn the exoskeleton on and off, as well as customize the torque to fit their personal comfort preferences and their current physical situation [5]. See Figure 1 for a visual of HAL and its main systems.

**FIGURE 1 [5]**

Side view of a patient wearing HAL with labels of the main components.

**Main Controller**

The main controller is essentially the “boss” of the machine. Its role is to regulate the power units and batteries, in addition to interacting with the system operator. It is the main controller that adjusts the proper torque required for the individual power units needed for walking, standing up, sitting down, and other movements. The main controller then relays the information from the sensors to the monitoring system which allows the user to make adjustments as needed [5]. There are two types of control systems used: the Cybernic Voluntary Control, and the Cybernic Autonomous Control.

**Cybernic Voluntary Control**

The job of the Cybernic Voluntary Control (CVC) is to provide physical support to the user based on his or her muscle activity. The CVC produces supportive torques in order to enhance the torque that is already produced by the user. The amount of torque required is calculated based on the bioelectrical signals received [5]. These signals are then used as the input command to regulate HAL and, once they are interpreted by the computer and the user’s intended movement is found, the computer decides the amount of assistance needed. Although the Cybernic Voluntary Control is successful in moving the wearer’s limbs, it is not able to alter or predict the user’s actions. This control method works well for people with physical disabilities whose bioelectrical signals are fully functioning. The CVC method, however, will not work for patients recovering from any type of incident resulting in brain damage, such as a stroke-related paralysis, due to the fact that their bioelectrical signals are not the same as that of a healthy individual [9]. To resolve this issue, HAL has an additional control system known as the Cybernic Autonomous Controller.

**Cybernic Autonomous Control**

The Cybernic Autonomous control does not use the user’s bioelectrical signals to produce the torque assistance, but instead uses a library of previously determined movements modeled after the typical motions of a fully functional body [5]. These previously determined movements are saved in a computer database that can be triggered automatically as soon as the wearer begins to move. The Cybernic Autonomous Control is also able to tailor HAL to each individual by remembering and storing their unique movement and force patterns in the computer for continued use [9]. As a result, the paralyzed user is able to maneuver independently with motions personalized to fit his or her needs.

**EMG SIGNALS**

In order to move as the wearer intends, HAL must receive and interpret the signals sent by the brain. When a person wants to move, an excitatory input is sent to the motor neuron that raises the membrane potential of the neuron and an action potential is produced. This action potential causes chemicals, known as neurotransmitters, to be released between the motor neuron and muscle. As a result, an electrical potential is produced in the muscles which can be recorded as electromyograms (EMG) by surface electrodes on the skin [8]. EMG is defined as the signal that records the electrical changes that occur in the muscle cell during muscle contraction and the nerve impulses that initiate this change [2]. In other words, EMG is a recording of the signals that control the activities of muscles. An apparent amount of EMG signal can even be produced by patients who are paralyzed [2].

HAL uses these signals to predict the wearer’s desired movement, and the robotic exoskeleton moves accordingly. When wearing HAL, bioelectrical sensors that read EMG signals are attached to the skin covering the extensors and flexor muscles of the knee and hip joint. A pattern recognition method is used by HAL to interpret the signals it receives. The pattern recognition method is broken up into two steps: feature extraction and classification. Feature extraction involves reducing the dimension of the raw EMG data to form
a feature vector which is calculated through features of segments of the data. The data is segmented in order to keep the structural detail of the signal. The features selected from the EMG signal are the used for the next step: classification. The classification technique used in this method is known as Artificial Neural Network (ANN). ANN is a nonlinear mapping structure that is based on brain function. Patterns of EMG signals are found using ANN which allow a new set of independent data to be produced as a predicted outcome [2]. Therefore, with this technology, HAL can predict the desired movement of the user.

A study performed at the National Institute of Technology Calicut by Dr. Sivanandan, George Teena and George Shalu demonstrated the effectiveness of the pattern recognition method, along with the classification technique ANN used in HAL. In the study, the pattern recognition method was compared to a threshold detection method. In the threshold detection method, muscle activity was detected by comparing the amplitude of the signal received by a threshold value. However, EMG signals between each person differ as a result of factors such as age, sex or skeletal morphology [2]. Due to differences in EMG signals, the threshold value for each person would be different. Therefore, this method would not work for a group of people, but only a select few whose threshold values are similar to the one set. The study also took a look at different classifiers. The first was the Support Vector Machine (SVM), but this classifier only distinguishes between two classes, rest and movement. The next to be tested was Linear Discrimination Analysis (LDA) which classifies movements at different speeds by expressing one dependent variable as a linear combination of features. The last one was ANN which, just like LDA, could classify movements at different speeds but by mapping structures and identifying patterns. ANN proved to be the most accurate method with an overall classification method of more than 90% compared to LDA, which had an overall classification of (80-83) % [2]. This study showed that the best way to interpret EMG signals in order to produce movement similar to that intended by the wearer is to use the pattern recognition method paired with the ANN classifier. The overall method described is better for a range of patients and will allow HAL to be better suited for each individual.

**PHASE SEQUENCING IN AUTONOMOUS CONTROL**

Once muscle activity is estimated using the data from the EMG signals, the robotic exoskeleton HAL executes the desired movements. A method known as Phase Sequencing was developed in order to ensure that the motions of HAL are “human-like” [3]. This method is based on recordings of the motions of an able-bodied person. Once patterns are established, the motion is divided into motion sequences, known as phases that break the motion down into components. By combining certain phases, full motion, such as walking or sitting, is obtained in an independent way [5].

Walking, for example, is divided into three phases. Phase 1 is the swing phase; as seen in Figure 2, the foot lifts from the ground and the leg swings forward. In phase 1, myoelectric signals are generated at the flexor muscle of the hip and at the flexor and extensor muscle of the knee joint. The myoelectric signals in the hip are generated due to a bending in the hip joint. The hip flexor is in active mode during this phase, meaning that a contractive force is generated and the muscle length is shortened, as seen in Figure 3 (a). The myoelectric signals in the knee joint are generated by the bending of the knee joint and its extended forward motion. The knee joint is in free mode, meaning that a force is not generated from the muscle but the muscle is still shortened; this is demonstrated in Figure 3 (c). The shortening of the muscle, in this case, is caused by a force generated by the thigh [3]. The combination of the movement of the hip and knee joint which make up phase 1 is shown in Figure 2. After phase 1 is completed, the leg is slightly lowered, setting the foot on the ground. In this second phase, the hip is slightly extended and the knee is slightly lifted, resulting in the production of myoelectric signals at the flexor and extensor muscles of the hip and knee joint. In phase 2, both joints are in free mode because no contractive force is generated [3]. The motion of phase 2 can be seen in Figure 2. Lastly, phase 3 is when the foot stays in contact with the ground in order to support the body. The hip joint, which is now in active mode, is extended, generating myoelectric signals at the extensor of the hip. The knee joint is slightly bent and then extended, resulting in myoelectric signals at the extensor of the knee joint. Here, the knee joint works in passive mode, meaning that the contractive force causes the muscle to lengthen, as seen in Figure 3 (c). The extensor of the knee joint is lengthened in order to absorb the shock from the upper body as the foot makes contact with the floor [3]. The combined motions of phase 3 are shown in Figure 2.

For phase sequencing to work properly, the phase-shift timing must be correct. The most effective way to determine this timing is through floor reaction force (FRF) [3]. FRF is the force applied to the foot from contact with the ground. In walking, for example, the leg begins phase 1 when the back of the opposite foot is in contact with the ground and FRF is detected there. Then phase 2 begins when the FRF shifts to the front of the foot of the leg in motion. Finally, phase 3 is indicated when the FRF is detected on the rear of the opposite foot [3].
A study was carried out at the University of Tsukuba by Hiroaki Kawamoto and Yoshiyuki Sanki that proved that the phase sequencing method is a successful method for the autonomous motions in HAL. The study that was conducted involved a healthy 28 year old male who wore a version of HAL that used Phase Sequence control. Their work showed that the activation levels of muscles were significantly reduced, the motions of the hip and knee were similar to that of motions without the power assist and the phases were successfully transited [3]. Therefore, from this work it was concluded that the Phase Sequence method described above allows HAL to successfully perform smooth, humanoid motion.

**CASE STUDIES**

Now that sufficient knowledge on the components of HAL and how they work together has been established, the next step is to prove the effectiveness of the device. In order to find out how well HAL actually works, its applications in the rehabilitation field will be analyzed. First, a case study involving a Hemiplegia patient will be described, followed by a similar study involving a polio survivor.

**Hemiplegia**

One example of an application of HAL would be for the rehabilitation of a Hemiplegia patient. Hemiplegia is the paralysis of one entire half of the body and is often caused by stroke. For people who have paralysis due to a cerebral vascular malfunction such as stroke, rehabilitation during the acute and convalescence stages is carried out in an effort to save as much motor function as possible. Patients past the chronic stage of Hemiplegia often have to live with daily discomfort, such as a circumduction gait or a foot drop gait in order to walk. Gait refers to a person’s manner of walking. Having a circumduction gait means that in order to walk, one must raise their hip to swing their limb in a circular pattern away from their body, while keeping their foot on the ground for support. Walking in this way can cause both hip discomfort, and discomfort in the unaffected leg due to the increased strain caused by swinging the affected leg. A foot drop gait is a walking pattern that is characterized by the inability to raise one’s foot at the ankle toward their body. This may lead to pain, weakness, and numbness. Walking with a foot drop gait becomes difficult because in order to compensate for their foot not rising high enough, one must overemphasize their steps to avoid tripping. People with these gait problems have to face these obstacles every day in order to carry out their life. A sustainable solution, in terms of improving the quality of life of people affected, would be the robot suit HAL. The ideal scenario would be if the hemiplegia
The patient could carry out movements similar to that of a healthy individual [10].

HAL is able to alleviate the defective motion by creating external forces on the paralyzed limb. According to Kawamoto, one of the researchers of this study, “Currently, one of the most important technical problems for these wearable robots is to obtain the user’s motion intention. Moreover, applications of the wearable robot to patients with paralyzed lower limb have been hardly reported” [10]. From this it is clear that HAL sets itself apart from other wearable robots due to this unique ability.

To test HAL’s effectiveness on a hemiplegia patient, clinical trials were conducted which focused on knee flexion support for those that struggle with bending their knee, but still have detectable bioelectrical signals from the injured knee. The trial subject was a 60 year old man with hemiplegia on the right side of his body, and every day he used a cane and wore ankle orthosis in order to walk. His walking could be described by a circumduction gait caused by the inability to flex his right knee joint without also flexing his right hip joint [10].

**FIGURE 5 [10]**

![Knee angle and bioelectrical signals of subject with the support of HAL.](image)

For a total of four weeks, trials were held once a week for an hour. When first standing evenly on both feet, the subject had to redistribute his entire body weight to his left which would then activate the right knee flexion support resulting in the production of bioelectrical signals as a cue for his right knee to bend. Once the right joint reaches a predetermined angle, the torque is dropped allowing him to extend his right knee on his own, redistributing his weight back on his right leg [10]. This procedure was repeated for seven successions with some of the device parameters being adjusted each time to optimize knee flexion support.

The data collected from this trial shows that the angle measured from the right knee during flexion made a notable increase when using HAL in comparison to knee flexion without the device. The patient’s knee flexion increased from around 30 degrees without the assistance of HAL, to three times that amount at a knee flexion of approximately 90 degrees with the assistance of HAL, as shown in figures 4 and 5. The data also showed that the bioelectrical signal sent from the impaired knee flexor was smaller with the assistance of HAL, which means that the paralyzed knee was able to exert less energy to create flexion [10].

This study demonstrates the sustainability of HAL in respect to improving quality of life. An increase in the flexion of the knee allows for a decrease in discomfort caused by an abnormal gait. HAL removes the need for assistance, such as that from wheelchairs which make it difficult to move around in tight spaces. HAL also makes it possible to walk up stairs because the patient’s knee can be bent to the appropriate angle required for the ascension of the foot.

**Polio**

Another example that demonstrates HAL’s effectiveness is its use in the rehabilitation for polio survivors. There are currently millions of people living worldwide who have survived after being infected with the poliovirus [11]. The poliovirus damages the body’s spinal cord cells and motor cells, causing the inflicted person’s muscles to become weak preventing voluntary joint movement, resulting in paralysis. Walking, climbing stairs, and moving around in small spaces is a struggle for these people and some survivors need assistance to move their limbs. They also have very weak bioelectrical signals in comparison to those of a healthy individual [11]. As a result, reviving mobility with the use of traditional rehabilitation techniques is strenuous for those who have been affected by the poliovirus.

A study was conducted with a polio survivor who had lost mobility in his left leg when he was 11 months old due to the virus. He currently has both extreme muscle weakness and paralysis in his left leg. Figure 6 is an image of the patient’s legs; one of which is affected by polio and the other is not. This image helps to give an understanding of the damaging effects of polio. The patient has been wearing a leg brace to straighten his knee while walking for a total of 50 years. The intention of this study was to produce a knee flexion motion based on the participant’s bioelectrical signals and the
assistance of HAL, so that the participant would no longer have to use a leg brace [11].

Electrodes were placed on the participant’s skin and he was given the ability to adjust the amount of assistance received by manipulating the interface unit on the device. The subject’s bioelectrical signals were then measured. The signal was documented at moments during which the strongest signal was received based on the user’s motive [11]. The focus of the study was on the movement of the participant’s knee flexion while he was standing.

After conducting the experiment, it was found that the participant was able to increase his knee flexion from an angle of 0.1 to 2.3 radians. HAL also enabled the participant to raise his lower thigh [11]. This shows that HAL was successful in increasing the participant’s knee flexion, through the assistive torque, even though the participant’s bioelectrical signals were very low and infrequent. HAL will help to relieve the discomfort often felt by these patients and allow the performance of daily tasks, such as walking and ascending stairs, to become easier. In doing this, HAL is able to improve the quality of life of its users, thus demonstrating its sustainability. These results could not have been produced through traditional rehabilitation techniques.

FIGURE 6 [11]

(a) (b)

Polio patient with healthy leg (a) verses leg affected by poliovirus (b).

ETHICAL CONCERNS

As a result of being a new technology, ethical concerns surrounding HAL have come to light. Ethical issues that are currently being addressed include the standardization of the device, injury resulting from technical malfunctions, as well as efforts to reduce the current cost of the robotic exoskeleton. A brief description of these issues are included in the next sections.

Standardization

The rise in production of human assistive robots has created the need for the installation of a system which guarantees user safety. High protocols are set for these robots because of their applications in nursing care and the assistance of the elderly and physically impaired. The problem is that technological improvements are being implemented without device safety measures being defined. Responsibility in the event of an accident needs to be decided as well as setting standards that customers can use to assess the safety of the device [6].

The International Organization for Standardization joined forces with the International Electrotechnical Commission to create the ISO/IEC Guide 51 which gives worldwide regulations for machine safety. Now that robots are operated by complicated algorithms, safety cannot be simply be guaranteed by controlling flawed components. A small error in the programming could cause dangerous accidents, therefore measures have been made to ensure software safety. The IEC 61508 describes these functional safety requirements for computer-based devices [6].

Injury

One major social issue involving robotic exoskeletons is injury of the user. These devices have been designed for household, nursing care, and clinical trial usage and it is inevitable that at some point a patient injury will take place. When this occurs, the question of who is responsible for the damages comes into play. The manufacturer of the device will receive the blame if the injured party is able to verify that there was an error in the product that led to their injury [6]. An assistive device such as HAL is more at risk for possible glitches due to its pre-programmed autonomous control that is not completely controlled by the user.

Price

Another social issue involving robotic exoskeletons is affordability. The advanced technical aspects of assistive devices comes with a high cost. Due to this high cost, only a small fraction of possible users will have the means necessary to purchase one of these devices. This creates a problem because it holds a large group of people back from the benefits of this assistive technology [12].

This brings up the topic of sustainability. A product that is too expensive for the majority of the population to purchase is considered economically unsustainable. For a technology to be successful, it must be readily available to those in need. If HAL stays at its current price, it would not be practical for potential users to purchase. One possible solution for lowering the financial burden caused by robotic exoskeletons would be by forming a collaboration with the companies who produce these devices. Another way to bring down the cost of
HAL is by mass production of the device; if the robotic exoskeleton is made efficiency and abundantly then the price will drop significantly.

HAL: THE ANSWER TO IMMOBILITY

Robotic exoskeletons, such as HAL, are the answer to immobility in patients whose neural pathways are not functioning properly as verified through the results of case studies. HAL allows the immediate recovery of voluntary movement as opposed to the need for multiple sessions of rehabilitation with conventional methods. In addition, HAL could be used as a daily tool for the recovery of patients suffering from some form of paralysis who do not have the ability to recover through physical rehabilitation. The mobility achieved through the use of HAL will open the door to vast opportunities for the user that were previously unattainable, resulting in an improved quality of life. Not only that, but HAL can also be tailored to fit the unique needs of each individual patient through the autonomous control which learns the user’s movement patterns, and the interface units which allow the user to adjust the device settings based on their personal preference. This adds to an improved quality of life for HAL users by allowing them to obtain optimal comfort. However with the implementation of this device, as with all novel technology, comes ethical concerns. There are potential injuries that can occur due to inevitable glitches in the hardware which is why standardization of these assistive devices is needed. The standardization process, however, can be very difficult due to the variety of applications of robotic exoskeletons. Currently organizations are working to resolve this issue. Another issue with this technology involves the economic accessibility to those in need. This issue could be mitigated through the collaboration of production and insurance companies. The use of cheaper materials that do not affect the quality of the device could also allow for the affordability of the device. The combination of these price reducing techniques will allow HAL to become the most economically sustainable rehabilitation option for those suffering from immobility. With this technology more readily available, HAL has the potential to revolutionize rehabilitation providing the assistance needed to ultimately improve the quality of life for all of its users.

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**ADDITIONAL SOURCES**


**ACKNOWLEDGEMENTS**

We would like to thank Judy Brink for all of her help in our search for applicable sources to use in our conference paper. We would also like to thank our co-chair Jessie Liu for all of her help with giving us advice and guidance, as well as taking the time to review our submissions.