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Development of a Mechanical Shoe Donning and Doffing Assistive Device for Bilateral Upper Limb Deficiency: A Prototype

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ABSTRACT

One of the most important problems for the bilateral upper limb deficient patient is the inability to don and doff their shoes. Assistive devices have emerged as a beacon of hope for bilateral upper limb-deficient patients, bridging the gap between their abilities and the activities they wish to perform. Mobility is a fundamental aspect of daily life, and footwear plays a pivotal role in this regard. For an upper-limb-deficient child, the simple act of putting on shoes can be a daunting task. The objective of this study is to design and create an effective mechanical device that can provide assistance to patients with bilateral upper limb deficiency facing challenges in independently donning and doffing their shoes and reduce the time and effort required to put on their shoes.

KEYWORDS: Bilateral amputee, upper limb deficiency, assistive device, shoe donning, shoe doffing

INTRODUCTION

Assistive devices are often recommended by prosthetics and orthotics professionals to improve the functional status of patients who have physical limitations. They substitute for impaired range of motion, muscular strength, endurance, manual dexterity, and mobility. The need for assistive devices is based on a therapist's appraisal of a patient's self-care skills and his or her motoric, cognitive, and attitudinal capacities to use the device effectively. Unfortunately, the prescription of assistive devices has not been accompanied by a systematic evaluation of device utilization.[1]

Individuals who have lost an upper limb often face challenges in performing certain tasks, leading to dissatisfaction. These tasks include activities such as using knives and spoons, chopping vegetables, fastening a tie around the neck, buttoning a shirt, trimming nails, carrying a tray, holding multiple packages, donning and doffing shoes, and tying shoelaces simultaneously. The absence of an upper limb can make these everyday activities more difficult, impacting the individual's overall satisfaction and independence in daily life.[2]

People with upper limb deficiency can benefit from various assistive devices. These tools help them do everyday tasks, making their lives better. With these devices, individuals with disabilities can be more independent and contribute actively to society. For disabled children, these tools are crucial for their thinking, physical abilities, and making friends. In simpler terms, these devices make life better for many people with disabilities.[3]

The use of adaptive devices for bilateral upper limb amputees is a must because the use of prostheses and functional outcomes is

limited and also provides limited range of activities. Major problems that a bilateral amputee faces include difficulty donning and doffing their shoes.[4]

Some shoe donors are available on the market, like heel cups, which the user easily puts in the shoe with his normal hand so that the user's foot can easily go into the shoe, but it becomes very bulky and difficult to take out the heel cup when the user's foot is completely inside the shoe. Some other examples of shoe horns are extra-long shoe horns, which help in shoe donning, but such devices are difficult to use, and the limb of one side of the body becomes necessary in fitting the aid into the shoe.[5]

There is little scientific evidence to support the use of shoe donning and doffing devices for children with bilateral upper limb deficiency. The goal of this study was to design a highly effective, portable, and easy-to-use device that allows an upper-limb-deficient child to easily and independently don and doff their shoe.

MATERIALS AND METHODS

Subjects

A 17-year-old girl was presented with a limb deficiency in the bilateral upper extremity. The patient has had limb deficiency since birth, due to which she has not been able to don and doff her shoes independently. The patient was recruited from DSMNRU, Lucknow. The age, gender, and other anthropometric data were collected, and a detailed explanation of the study was given to the patient after they signed an informed consent form.

Methodology

This new and innovative design generally needs a proper design blueprint along with an empirical thought process. A more accurate device was produced with a suitable blueprint. This is made of cast iron. This design was fabricated from the following components, such as:

1. Iron sheet of 0.5 mm and 35 cm/sq
2. Iron channel of length 8.3 cm
3. 2 coil compression springs of diameter 4 cm and height 7 cm
4. Extension spring of width 2 cm and height 6 cm
5. Wheel bearing of diameter 3.5 cm
6. Plastic shoe horn of length 19 cm.

Figure 1. Expansion Spring

Figure 2 Coil spring

Figure 3. Plastic shoe horn

Fabrication Procedure

The shoe donning and doffing device (Figure 4) involves several steps in the fabrication procedure.

Firstly, the iron sheet was first cut like a platform on which the entire structure could be built. Another pair of plates of iron sheet were cut, which is like a sole; one plate was cut in the shape of a hind foot and the other plate was cut in the shape of a forefoot, and the size of both plates was 8×8. Both plates are joined together by an expansion spring, which is connected to the cutting ends of both plates. A wheel bearing was attached to the bottom of the forefoot plate in such a way that it could rotate while remaining fixed in its place.

A wheel bearing was added to the downward anterior portion of the forefoot plate in such a way that it could be fixed in place and rotated. Both the hind foot plate and the forefoot plate are attached to each other by a spring, and a wheel bearing is placed under the forefoot plate. An iron channel is fixed at the front above the base platform, under which the fixed wheel bearing under the forefoot plate can rotate and move forward with the help of an expansion spring.

Below the hind foot plate, two coil springs were vertically joined with the base platform so that the hind foot plate could be compressed downward. In order to provide mediolateral stability to the whole structure, 4 iron pillars were placed on the side of the device, in which 2 pillars are on the left and right sides of the forefoot plate and the remaining 2 pillars are on the right and left sides of the hind foot plate. The base platform was added together so that the device could not be bent to the left or right side.

An iron sheet whose diameter is 1 mm is joined vertically from the back of the iron base plate, which stands vertically behind the just hind foot, whose height is 16.5cm. The width of this vertically attached iron sheet is 2.8 cm, and its upper end is bent into a U shape, and a hole is made in it so that the plastic shoe horn can be fixed.

Another small piece an iron sheet is attached in an inclined shape to the front border of the forefoot plate, whose width is 2 cm and height is 5 cm, which acts as a barrier. When placed on the plate, this barrier will prevent the foot from coming out.

To move the forefoot plate forward with the help of a wheel bearing, channel, and expansion spring, an iron channel was made in an L shape, and the side borders of both plates were fixed so that the forefoot plate could move forward.

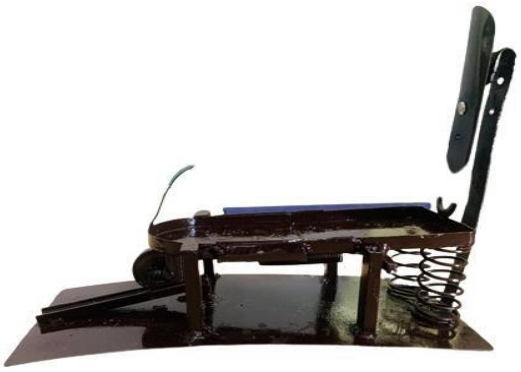

Figure: 4 Shoe Donning and Doffing Device

WORKING MEACHANISM

The assistive device for donning and doffing shoes is a bit complex, as it involves different metallic components working together to fulfil the design's purpose. Firstly, an iron sheet platform will be fixed to the floor by drilling it, ensuring that the platform is securely attached to the floor. When the user uses the device, it will remain fixed in its position for stability. Afterwards, the user will insert the forefoot part of their foot, along with their shoes, onto the base plates of the device. The plastic shoe horn, located behind the device, will hold the vamp area of the shoe while the user inserts the heel part of their foot into the shoe. This ensures a proper fit of the shoe over the heel. By this action, the patient is now fully dressed, his shoe on his foot. Then, to release the shoe from the shoe horn, the user will apply downward force to the heel part, pressing it against the footplate. This action compresses the coil spring, causing the hind footplate to move

downward, away from the shoe horn, and the shoe horn, which is fixed in its place, to be released. The patient can then comfortably exert anterior force on the forefoot plate's border and barrier, causing the forefoot plate's wheel bearing to rotate on its iron channel. As a result, both plates' borders will slide and move forward, allowing the patient's foot to be easily released from the shoe horn.

The patient's shoe will be securely fastened to their foot in a complete manner, after which the patient will comfortably remove their shoe and foot from the device. Then, when the user needs to take off their shoes, they will place their foot, including the shoes, on top of the device, and the user will insert the back part of the shoe into a shoe horn and effortlessly slip their foot out of the shoe, leaving the shoe on the device. This way, when the user needs to wear shoes again, they won't have to search for them separately.

RESULT & DISCUSSION

The result of the present study suggested that the mechanical shoe-donning assistive device proved to be an effective solution for individuals with upper limb deficiency. The mechanical shoe-donning assistive device is capable of effectively assisting users with weights up to 25 kg whose shoe length is 18 to 23 cm and width is 8 to 10 cm in the process of donning and doffing shoes.

Its design and lightweight construction make it suitable for individuals with lower body weights, promoting their independence and improving their daily living activities.

The device successfully automated the process of donning and doffing shoes, reducing the dependence on caregivers or the need for additional assistive tools. The subjects who participated in the study reported a high level of satisfaction with the device, as it improved their independence and reduced the time and effort required to put on their shoes.

The result of this study contributes to the advancement of assistive devices and highlights the importance of user-centered design in creating impactful solutions. With continued refinement and further research, the mechanical shoe-donning assistive device has the potential to transform the lives of individuals with limited mobility of the upper limbs, promoting their independence, well-being, and overall quality of life.

One of the main strengths of the device was that it was user-friendly. The mechanical components were carefully selected to ensure ease of use. The feedback from the participants indicated that the device was comfortable and easy to operate, contributing to its overall effectiveness.

Another significant finding was the positive impact of the device on the user's quality of life. The device enhanced their sense of dignity and autonomy by enabling them to perform a basic activity of daily living independently. It reduced the frustration and embarrassment often associated with relying on others for assistance with simple tasks like putting on shoes. This improvement in psychological well-being is a crucial outcome and underscores the importance of assistive devices in promoting independent living for individuals with upper limb deficiency.

These findings were consistent with those of Harriett S. Bynumet et. al., who concluded in their study that shoe horns are commonly used by elderly patients, being used by subjects in one survey of patients aged 80. Factors to consider when choosing a shoe horn are the mode of putting on shoes and the degree of spinal rotation and ankle movement. For those who can stand or who have poor hip movement, a long shoe horn is preferable, the optimum length being between 53 and 63 cm. When there is limited back mobility or reduced ankle movement, a shoe horn with a stiff spring will help. The length of the leg from knee to heel should be assessed; too long a shoe horn is difficult to use from a sitting position. Shoe horns with a built-up handle are available to improve the most popular plastic shoe horn, which has a hook floor and foot. [1]

According to Carissa Black et al., who developed a knee nook device that is capable of assisting the shoe-donning activity with a single hand, patients with upper limb functional loss face trouble putting their feet into shoes without crushing. To avoid this problem, a custom shoe horn lever is proposed to assist the user in inserting their foot comfortably inside the shoe without crushing the heel once the shoe horn is placed on the shoe. The device works like a regular shoe horn; the user simply puts it on the back of his shoe, allowing the foot to slide forward easily.[5]

CONCLUSION

It can be concluded that the mechanical shoe donning and doffing device is capable of effectively assisting users with weights up to 25 kg whose shoe length is 18 to 23 cm and width is 8 to 10 cm in the process of donning and doffing shoes. Its design and construction make it suitable for individuals with lower body weights to don and doff shoes independently, improving their independence and daily living activities. The outcomes of this study contribute to the advancement of assistive devices and highlight the importance of user-centered design in creating impactful solutions. The device can be an efficient solution for independent shoe-donning activities. The participants reported a high level of satisfaction with the device, as it improved their independence and reduced the time and effort required to put on their shoes.

LIMITATIONS

Despite these positive findings, there were some limitations to the current device. Firstly, the sample size of participants was relatively small, which may limit the generalizability of the results. The choice of materials used in the design may pose limitations for users who require a lightweight solution.

FUTURE DIRECTIONS

Further research should investigate the long-term effects of using the device and its potential for wear and tear over time. Additionally, instead of using springs, we can enhance this device in the future by transforming it into a sensor-based system powered either through electrical impulses or battery technology. This evolution revolutionizes its functionality and versatility.

Authors' Contribution

The entire clinical course of development of a mechanical shoe donning and doffing assistive device for children with bilateral upper limb deficiency service was done by Mr. Navneet Tiwari towards the fulfilment of a bachelor's degree research project under the guidance of Mrs. Rohina Kumari. The manuscript preparation is done by Mrs. Rohina Kumari. All the clinical service and research study was carried out in the premises of DSMNRU, Lucknow.

Declaration by Authors

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