ROLL WITH IT

ALL-IN-ONE ASSISTIVE MOBILITY DEVICE FOR CHILDREN WITH MOBILITY IMPAIRMENTS

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Problem Statement/Research Question and Background

There are many children living with mobility impairments around the world. These mobility impairments range in degree of severity and the parts of the body they effect. These impairments can either be genetic or manifest later in an individual's life for a variety of reasons. Cerebral Palsy (CP) is a common example of these impairment disorders that affects motor function in different parts of the body. CP causes impairments with gait, muscle tone, posture, and coordination of movement to varying degrees of severity. It is the most prevalent childhood physical disability, with 1 in every 300 children being born with CP [1].

A study done by S. Boulet showed that 41% of children with CP had difficulties with crawling, walking, and running, and 31% needed special assistive equipment. Similar statistics apply for various other mobility impairments. Typical mobility devices include wheelchairs or walkers, however these devices range from $ 1050 – 5200, depending of the severity of the condition [2]. The average household in Canada makes only $ 57,000 per year, making this an unaffordable option for many [3]. This is also the case in developing countries, as income rates are lower and accessibility to these devices are minimal. For example, in India the average annual family income is 32,100 INR ($ 616) [4], however, the average annual cost for a patient with CP is upwards of 8129 INR [5]. Therefore, in addition to the physical and mental difficulties an individual with a mobility impairment will face, there is also a significant financial burden.

The need for an affordable and effective mobility device is apparent. As mobility disorders have multiple degrees of severity, impacting every individual in a different manner, it's important that a device is able to accommodate each child's needs. Factors that need to be taken into consideration include the child's size and various additional components that would be required based on the child's dependency on the device. For example, a ten-year old with minimal impairments would require a sufficiently different device than a three-year old with more severe motor impairments impacting their gait and ability to support their body weight. A device that addresses these problems would be of high demand not only in North America, but worldwide. As a result, this device would need to be easily shipped and assembled.

Continuing to use, Cerebral Palsy as an example, about 77 percent of children with CP suffer from spasticity; 41.8 percent could not walk independently. Another 30.6 percent had no ability to walk at all [6]. This greatly affects the ability for people with these mobility impairments to complete everyday tasks as simple as getting from one room to another, and typically end up relying on a caregiver. An assistive device has the ability to greatly increase the individual's quality of life by allowing them to be more self-sufficient. A device satisfying these needs has the potential to make a difference in the lives of people not only with CP, but with any mobility disorder. Therefore, if this device was made accessible around the world, it would have the capacity to make a global impact.

Methods/Approach/Solutions Considered

Queen's Biomedical Innovation Team is committed to empowering innovation through engineering curriculums to promote interdisciplinary collaboration to solve problems within the field of biomedical engineering. Roll With It (RWI) recognized that the immersion of accessible design is severely lacking in the developing world; specifically, regions of low-income. Lack of accessibility to proper devices places limitations on individuals with mobility impairments, restricting their ability to integrate and function in society. Acknowledging this, RWI decided to explore solutions that improve the accessibility, and ultimately quality of life of individuals with mobility impairments.

Preliminary research was conducted to expand the teams understanding of the different aspects impacting the functionality of individuals with mobility impairments. A user profile was constructed that provided a detailed description of the physical and cultural restrictions that these individuals face in their everyday lives. In addition, population dynamics were completed to explore the demand and availability of mobility devices in the current market. In-depth analyses of materials were done in order to ensure our design would tolerate a range of different environments and demands placed on it. This was done by reviewing previous designs currently on the market, as well as knowledge from previous coursework experience. Considering all the implications of mobility devices, and further understanding our target population, allowed the team to place more of an emphasis on where considerations should be primarily focused in the proposed design solution. The project scope was initially defined to provide an affordable multistage assistive mobility device for children ages 3-10 diagnosed with Cerebral Palsy in urban India. The team worked to produce a design that would provide the necessary aides to a child as they mature into adolescence. The design required incorporation of cost-efficient, locally sourced materials to provide an affordable solution. The concept was initially intended to encompass 3 interchangeable modes of assistance: a super crawler, seated-assistive walker, and assistive walker. As the patient matures, the interchangeable modes address individual motor impairment needs, which not only promotes independence, but also helps integrate individuals into functional daily living and social situations, such as school. The project team ensured to follow the Seven Principles of Universal Design to provide a feasible product within the defined scope.

The project managers refined the preliminary prototype and consulted industry professionals, including Masters/Ph.D. candidates, Professors, and Clinal Professionals. These individuals advised the team to focus on the concepts ability to improve an individual's mobility, rather than their condition. Through multiple iterations of parallel designs, the team incorporated positive elements of several preliminary solutions to provide an optimal final design solution. Progressing further, the team began a trial and error phase through the construction of a preliminary prototype. This aided the team in gaining a better understanding of the operating mechanics of the device and challenges the user may encounter during operation. The team recognized the vast diversity in juvenile development and determined that multiple sizing options would allow the user to customize the device to cater to their personal needs. The final design offers three customizable combinations to accommodate the severity of the patient's condition. This provides individual's with mobility impairments the largest degree of freedom, mobility, and independence to promote engagement into their surrounding environments.

Description of Final Approach and Design

The current prototype was achieved through numerous iterations of feedback provided on each design. Through the communication with Master/Ph.D. candidates, University Professors, and Clinical Professionals, the final prototype was fine-tuned to ensure a universal design for the user. An analysis of the prototype operation at home, school, and during play was completed to maximize the functional time and minimize the required strength during movement. The final concept is a low cost, globally accessible mobility aid for children with mobility impairments. The device is customizable, with the user being able to choose one of three combinations with multiple sizing options to accommodate various degrees of gross movement complications.

The first option was adapted for crawling to ensure inclusion when playing, reading, or socializing on the floor level. The base width was increased for stability to ensure that the user remains comfortably positioned without the risk of slipping off. The second option was adapted for gross movements through the application of walking. Once strapped into position, the user will have the ability to maneuver at home to increase their strength and gain the ability to walk with classmates at school. In the school environment, the addition of a school bag hanger was a potential option and was placed directly behind the user to ensure that the mass equilibrium of the design was not offset. Additionally, during walking, the user will have the ability to grip onto the handles while their forearms are comfortably cushioned with padding. The third option includes the previous two with a further adaptation of a cushioned seat. The user will have the ability to lower the location of the straps from the walking position and ensure that they are kept in an upright seated position that decreases the load on the intervertebral discs. This option would allow the user to work at a school desk and have the ability to be seated during assisted movement. Footrests were included to remove the user's feet from the ground to ensure easy design movement and user comfort. Padding was placed on the posterior bars to the user's head to decrease the impact force upon any unforeseen events. The third option with additional seat padding attached, is shown below in Figure 1.

Figure 1: The full assembly walker with additional seat padding.

Through a user-friendly website, the customer will be able to select what option they wish to purchase. Depending on the preferences and financial situation of the user, they will be select additional add-ons to the device, including such attachments as an external satchel, arm padding, foot rest, and various others. What makes this concept so unique is that the user can then ship the device their house within a few weeks. This reduces the wait time experienced by current assistive mobility devices and eliminates the need for doctor approval. The device will arrive at the user's house disassembled, except for a few small areas where parts that are cemented together. With the aid of a detailed instruction manual, much like what IKEA provides with their furniture, the user will assemble the remaining parts of the device.

Outcome

After constructing a preliminary functional prototype, a local Occupational Therapist and Master's Student in Kingston, that work with assistive technology, were consulted. The physical design and potential application of the product/service were the primary discussion topics discussed during the meeting.

One of the main feedback points for the physical prototype was they stressed the importance of stability while in a seated position. Core support is a vital component in assistive mobility devices, especially those that utilize a seat. If the individual does not have adequate support, it can lead to various detrimental effects. The consultants believed the use of the harness would provide the necessary support to keep the user in a comfortable upright position. They also emphasized that safety, comfort, and stability were the three most important design concepts to keep in mind. They had concerns in the application of the device in outdoor settings, especially in developing nations and areas where the terrain is harsh. However, the purpose of the device is to aid in inside settings. Thus, the consultants were confident in the ability of the device to efficiently operate in the desired context. To further ensure the safety and reliability of the physical device, select components of the frame were solidified together using industrial grade PVC cement. They also recommended including cushioning to increase the user's comfortability while operating the device. However, they also recognized the importance of the concept behind keeping it as low cost as possible. Therefore, we decided to include an option for customers to purchase the cushioning as an add-on, thus giving individuals the option to keep the total cost as low as possible. Another comfortability issue they brought up was the concept of having the user's legs dangling over the edge of the seat if they weren't tall enough to reach the floor. Therefore, a foot rest was recommended to mitigate this issue. However, for the same reasons as before, a foot rest will be an additional add-on to the device for extra cost. Another major topic of conversation was the potential application of the device. The occupational therapist worked with a local school, and thus was interested in the potential the device had at improving a user's accessibility in the school setting. They mentioned that with a bit more fine-tuning of the device, they would be comfortable suggesting and implementing the device into schools even in Canada. They also were strongly enthusiastic about the concept of having the device be customizable on an online website, with the product being delivered to the user's door without clinical consolation/approval. According to the consultants, assistive devices in Canada can take up to a year to be delivered to the user, with conditions even worse in developing nations.

Cost Analysis

Table 1 below shows the cost breakdown for the three main device configurations for RWI (crawler, walker, full set). A single prototype cost was determined for each configuration using current market prices for the one-time purchase of the listed components through the website https://www.mcmaster.com/. A mass-produced cost per unit was determined assuming the production of 500 devices at a time. The material costs for the mass-production breakdown were taken from the global e-commerce website https://www.alibaba.com/. For the sake of clarity, the cost of shipping the components was neglected for both cost evaluations. However, a one-time cost to ship the ready-to-assemble device from Toronto, Ontario to Thunder Bay, Ontario was estimated at about $50.00. It is clear to see from Table 1 below that utilizing economies of scale drastically decreases the production cost of the RWI device.

Table 1 - Cost breakdown for the three main RWI configurations.

Crawler (USD)			Walker (USD)			Full Set (USD)		
Components	**One-Time**	**x500**	**Components**	**One-Time**	**x500**	**Components**	**One-Time**	**x500**
Total Pipe (262.67 cm)	$ 9.89	$ 2.63	Total Pipe Sm (575.22 cm)	$ 22.00	$ 5.75	Total Pipe Sm (575.22 cm)	$ 22.00	$ 5.75
Tool Clip (x4)	$ 8.36	$ 1.00	Total Pipe Med (673.8 cm)	$ 25.72	$ 6.74	Total Pipe Med (673.8 cm)	$ 25.72	$ 6.74
Expanding Caster (x4)	$ 120.00	$ 16.00	Total Pipe Lg (795.7 cm)	$ 30.38	$ 7.96	Total Pipe Lg (795.7 cm)	$ 30.38	$ 7.96
ABS Slab	$ 10.00	$ 1.00	90 Joint (x6)	$ 21.00	$ 1.20	90 Joint (x6)	$ 21.00	$ 1.20
90 Joint (x2)	$ 7.00	$ 0.40	Wye (x2)	$ 12.54	$ 6.00	Wye (x2)	$ 12.54	$ 6.00
3-Way Joint (x2)	$ 6.30	$ 0.40	Tee (x6)	$ 63.90	$24.00	Tee (x6)	$ 63.90	$24.00
			Cross (x2)	$ 7.20	$ 4.50	Cross (x2)	$ 7.20	$ 4.50
Total	**$ 161.55**	**$ 21.43**	4-way (x4)	$ 12.60	$12.00	4-way (x4)	$ 12.60	$12.00
			Cap (x4)	$ 3.12	$ 0.40	Cap (x4)	$ 3.12	$ 0.40
			45 Joint (x2)	$ 3.28	$ 2.00	45 Joint (x2)	$ 3.28	$ 2.00
			Expanding Caster (x4)	$ 120.00	$16.00	Expanding Caster (x4)	$ 120.00	$16.00
						Tool Clip (x4)	$ 8.36	$ 1.00
			Total	**$ 321.74**	**$86.55**	ABS Slab	$ 10.00	$ 1.00
						Plate Casters	$ 24.00	$ 4.00
						Total	**$ 364.10**	**$92.55**

To keep the cost of these devices as low as possible there will be no need for independent manufacturing. The device is made exclusively out of commonly found, pre-existing parts. This lowers the overall cost by avoiding tooling, engineering hours, and other overhead costs. The crawler configuration would sell for $75 USD plus relevant shipping costs. The walker configuration would sell on the website for $150 USD plus relevant shipping costs. The full-set configuration would sell for $175 USD plus relevant shipping costs. As the purpose of this product is to provide accessible assistance to as many families as possible, these selling prices are based on projected break-even prices for each configuration at a production scale of 500 units.

Significance

Individuals with functional motor impairments face barriers every day that restrict their ability to function habitually within society. Often, working assistive devices can diminish barriers, thus allowing these individuals to ambulate independently rather than rely on others for assistance in daily activities. Assistive devices such as walkers, chairs, and crawlers enable individuals with functional motor impairments the ability to stand unassisted, sit upright, as well as socialize face-to-face with peers. The Roll With It assistive device proposed by this team accomplishes these tasks through several aspects of its unique design. Using a sturdy frame, seat and supportive chest straps, this device is designed to assist the user in bearing their own weight during ambulation and supporting their trunk for sitting upright. By enabling the user to mobilize and support themselves with increased independence, this device makes it more possible for the user to go to school, eat meals at the table with their families, ambulate independently, and interact with their peers' eye-to-eye. Assistive devices currently on the market that aim to accomplish these tasks can cost on average between $400-$500, can are often only made available with a physician’s order [7]. These devices can take up to a year to be shipped to the user in developed nations such as Canada. This situation only worsens in developing nations such as India. Such significant constraints for these assistive devices place them well out of the reach of many families, resulting in a lack of acceptable support for a large portion of children with functional motor impairments. The significance of the Roll With It assistive device is to provide not only a cost-effective option, but also offer unique, quality support tailored to the functional motor impairment needs of each individual.

Acknowledgements and References

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