Perspectives on Leveraging Advancements in Adult Upper Limb Prostheses to Improve Pediatric Device Acceptance

Marcus A Battraw[1], Wilsaan M Joiner[2], Michelle A James, MD[3], Jonathon S Schofield[1]

[1]*Department of Mechanical and Aerospace Engineering, University of California, Davis, Davis CA, USA*
[2]*Departments of Neurobiology, Physiology and Behavior; Neurology, University of California, Davis, Davis CA, USA*
[3]*Shriners Hospital for Children - Northern California, Sacramento CA, USA*

ABSTRACT

There are many complex factors that contribute to whether a child with a congenital limb difference will use or abandon their prosthetic limb. When compared to adults with traumatic amputations, children with limb deficiencies are less likely to use a prosthesis, and many of their challenges are unique to being a child. Ultimately, for a child to adopt their device, it must facilitate the effective performance of daily activities and allow the child to be treated the same as their peers. Although numerous pediatric devices are available, they often fall short of these criteria by offering a single open-close grasp and/or non-anthropomorphic appearances. However, when looking to the field of adult prosthetics, multi-articulating myoelectric hands can provide multiple grasping configurations and have the benefit of a more 'hand-like' appearance. If these designs are adapted for pediatric users, their advantages have the potential to improve device acceptance. In this paper we provide a critical assessment of the state of upper limb prostheses for pediatric populations. Furthermore, we suggest ways that we may leverage recent advances in adult myoelectric devices to begin removing the barriers to pediatric device adoption. Finally, we discuss how current challenges in the adult myoelectric field must be considered to effectively translate this technology.

INTRODUCTION

It has been estimated that congenital transverse below elbow deficiencies occur in approximately 1 of every 10,000 live births [1]. For these children, a passive prosthesis may be prescribed as young as 6 months of age and active devices as early as 18 months [2]. The use (and/or abandonment) of these prescribed devices is a multi-dimensional challenge. Parents play a vital role in the decision-making processes that influence use and adoption while their child is too young to make these decisions for themselves. It is common for guardians to view their child's limb difference as a deficiency that needs to be addressed with an artificial limb [3]. However, when the child comes of age to make their own decisions, prosthetic abandonment quickly become more common [4].

Much like adult upper limb (UL) prosthetic users, device abandonment is a common occurrence; however, in pediatric populations it is a more prevalent and pervasive issue [5,6]. In 2007, Biddis and Chau reviewed 25 years of literature and suggested that adult prosthetic abandonment rates varied from 26% for body-powered devices to 23% for electric [5]. They further suggested that children face far more complexity in the prosthetic arena, resulting in abandonment rates for body-powered and electric prothesis at 45% and 35%, respectively [5]. Regardless of age, the key factors that ultimately impact use and acceptance of prostheses can be placed into three categories: social, prosthetic/technical, and clinical/personal factors [5]. Appearance, functionality, and weight can be further isolated as being particularly relevant to children [4,7], and *prosthesis usage is ultimately contingent on providing sufficient functionality and cosmesis to allow the child to be treated the same as their peers (social integration)* [8].

In this paper, we critically assess the state of UL prostheses for pediatric populations with congenital limb differences. Furthermore, we summarize the prevailing technical and social challenges that prevent the wider spread adoption of these devices. Finally, we suggest ways that we may leverage recent advances in adult myoelectric prostheses to begin removing the barriers to prosthetic acceptance and reduced abandonment rates in pediatric populations.

CURRENT PEDIATRIC PROSTHESES OPTIONS

Current pediatric prosthetic devices will either be passive (cosmetic), body powered, or myoelectric devices. Although passive devices may often appear more life-like or anthropomorphic in appearance, they lack critical functionality as they do not provide the ability to actively grasp. Body powered prostheses may offer many attractive qualities including minimal weight, cost, ease of control, and robustness. However, most of these devices are limited to a simple open-close grasp which inherently requires the user to employ compensatory strategies to achieve many daily grasping tasks. When coupled with their often-non-anthropomorphic appearances, body powered devices simply do not meet the functional and cosmetic demands to promote social integration. Current pediatric myoelectric devices typically offer a single degree of freedom (open-close) terminal device and in some cases wrist rotation. They provide the benefit of control using the muscles native to the affected limb which may remove the need for additional cables and harnessing as well as body/shoulder movements to control the terminal device. However, myoelectric devices come with a number of practical challenges including increased weight, often reduced robustness [7], slower actuation of the grasper, and challenges achieving consistent control.

Presently, body-powered prostheses are often preferred to myoelectric devices when performing functional tasks [9]. Crandall et al. surveyed the satisfaction of pediatric patients and their parents in relation to using their prosthetic device during daily activities. In their cohort of 34 users between the ages of 1 to 12 ½ years, body-powered devices were able to achieve more functional tasks to the users' satisfaction when compared to passive and electric devices. Surprisingly, in a long-term follow up more than a decade later, most of these same patients were using a passive device [9], suggesting that *the current single degree of freedom grasping function provided by an active prosthesis offers limited benefit relative to no-grasping function at all*. As a result, these patients opted to use a passive device that, although less functional, may provide improved cosmesis to help facilitate social integration. Further empathizing the magnitude of these challenges, in a survey-based study of 489 children with a unilateral congenital below-the-elbow deficiency (321 prosthesis users and 168 non-users), James et al. found no clinically relevant differences between prosthesis users and non-users in validated measures of functional outcomes and quality of life [10]. Furthermore, when investigating the performance of various daily tasks, they found non-users scored themselves higher than prosthetic users. This guided their conclusion that pediatric prostheses may provide cosmetic benefit for social acceptance or may be useful tools for specialized activities, but at present, they do not appear to improve patient function or quality of life [10].

GRASPING PATTERNS AND DAILY FUNCTION

Unlike the single degree of freedom grasping function offered by current active pediatric prostheses, healthy intact hands are incredibly dexterous with 27 degrees of freedom [11]. Although it is possible to achieve a multitude of complex postures with this available dexterity, most activities of daily living are performed using a limited number of common hand grasp configurations [12,13]. In fact, it has been suggested that nearly 80% of common daily tasks can be accomplished with as few as 6-9 standard grasp configurations [12]. Therefore, we suggest that a significant functional benefit may be provided to pediatric prosthetic users if their devices offer multiple grasping configurations to more effectively accommodate the performance of daily activities. This challenge is not unique to pediatric prosthetic users and closely parallels a very active body of work being performed with adult amputee populations.

LOOKING TO ADULTS

In recent years, multi-articulating adult myoelectric prosthetic hands have become increasingly available. There are now numerous commercially available options with individually actuating digits that can achieve a multitude of common grasping configurations [14]. Table 1 adapts data from a metanalysis of hand grasp literature [12]. Here, we list the top 6 most frequently used grasp configurations by intact hands in daily activities and compare them to the capabilities listed in manufacturers' literature of prevalent adult multi-articulating myoelectric hands [15–20]. Nearly all the top 6 hand grasp patterns are capable of being achieved with these current adult devices. Beyond their added function, an additional advantage inherent to their hand-like designs is that these prosthetic devices also appear more anthropomorphic or life-like than many of their body-powered hook-and-cable counterparts.

Together the added function of multiple grasp patterns and the improved cosmesis of adult myoelectric hands has the potential to address two crucial factors that influence pediatric prosthetic use. In fact, multi-articulating prosthetic hands are beginning to emerge in the pediatric field. For example, the Vincent Young 3 (Vincent Systems, Karlsruhe, Germany) is sized for children age 8 and up, is capable of 13 individual grasp patterns, has four wrist options, and is made of lightweight materials. However, these devices have only started to become available and have yet to see widespread adoption. There are a number of practical and clinical challenges that will likely first need to be addressed.

MOVING FORWARD WITH PEDIATRIC PROSTHESES

There are many considerations and barriers to multi-articulating myoelectric devices that may be both common and unique to pediatric and adult populations. Device cost is a significant and prohibitive barrier for both populations. However, it is a distinct obstacle for pediatric patients as their limbs and body are ever-growing. Therefore, unlike adults where purchasing a single terminal device may be a long-term investment, the cost of children's devices must reflect the fact that a child will likely outgrow a device in a few short years and multiple devices will be purchased over their childhood.

Table 1: Commercially Available Adult Multi-Articulating Adult Prostheses and Most Frequent Grasp Configurations used in Daily Activities.

Grasps / Prostheses	Power Grip	Precision Pinch	Key Grip	Tripod	Precision Disk	Prismatic 2 Finger
BeBionic	✓	✓	✓	✓	✗	✓
i-Limb*	✓	✓	✓	✓	✗	✓
Michalangelo Hand	✓	✗	✓	✓	✗	✓
Vincent Evolution 3	✓	✓	✓	✓	✗	✓
Luke Arm	✓	✓	✓	✓	✗	✓
Taska Hand*	✓	✓	✓	✓	✗	✓

Note: Prosthesis grasp data derived from available manufacturers' literature Activities [15–20], and Grasp configurations adapted from Feix et al. [12].
**prostheses allow for custom grasps to be programmed.*

Furthermore, the growth of a child also poses a unique barrier to achieving consistent myoelectric control. As affected limb proportions changes so will socket fit and the contact of electrodes over muscle control sites. This may result in diminished, inconsistent, or intermittent device control. In addition, most pediatric patients are born with their limb difference. Effective contraction of muscles on the affected side will inevitably require structured training and learning prior to being used for prosthesis control. However, here again we may look to advancement in the adult prosthetic field to mitigate some of these barriers. Commercially available control systems that employ myoelectric pattern recognition may be a viable option in alleviating some of these control challenges and facilitating intuitive control over multiple grasp configurations. Similarly, emerging experimental techniques that leverage ultrasound-based control or force-myography may also provide avenues for further investigation [21].

Finally, robustness and 'bulk' of a myoelectric hand have unique and interconnected implications to pediatric prosthesis use. When comparing activities of daily living between adults and children, we suggest that children will likely require a more robust device to facilitate the physical nature of childhood play. Robustness typically comes at the cost of a more rugged design with increased weight. Children are more affected by the weight of the device [22] as they are smaller and do not possess the same strength as a grown adult. Furthermore, multi-articulating prosthetic hands are innately heavier as they require motors and additional mechatronics to actuate digits. This additional componentry must also be housed within the device which may impact its overall size. Therefore, as multi-articulating pediatric prosthetic hands continue to emerge, significant attention must be dedicated to developing devices that incorporate lightweight materials and creative 'low-bulk' design principles.

CONCLUSIONS

The factors that contribute to the use and acceptance of pediatric UL prostheses are complex and abandonment is highly prevalent. There have been many advancements in adult UL prostheses that have yet to be leveraged which may positively impact the pediatric arena. By adapting the capabilities of adult multi-articulating myoelectric prostheses, we can begin addressing some of the crucial factors that are contributing to the disuse of pediatric devices. However, there are numerous challenges that are unique to this patient population that must be carefully considered to inform and shape the development of future multi-articulating pediatric prosthetic limbs.

REFERENCES

[1] A. G. Ekblom, T. Laurell, and M. Arner, "Epidemiology of congenital upper limb anomalies in 562 children born in 1997 to 2007: A total population study from Stockholm, Sweden," *Journal of Hand Surgery*, vol. 35, no. 11, pp. 1742–1754, 2010, doi: 10.1016/j.jhsa.2010.07.007.

[2] Y. Shaperman, Julie, Landsberger, Samuel, Setoguchi, "Early Upper Limb Prosthesis Fitting: When and What Do We Fit," *PROSTHETIC AND ORTHOTIC SCIENCE*, vol. 15, no. 1, pp. 11–17, 2003.

[3] E. Vasluian *et al.*, "Opinions of Youngsters with Congenital Below-Elbow Deficiency, and Those of Their Parents and Professionals Concerning Prosthetic Use and Rehabilitation Treatment," *PLoS ONE*, vol. 8, no. 6, 2013, doi: 10.1371/journal.pone.0067101.

[4] K. Postema, V. van der Donk, J. van Limbeek, R. A. J. Rijken, and M. J. Poelma, "Prosthesis rejection in children with a unilateral congenital arm defect," *Clinical Rehabilitation*, vol. 13, no. 3, pp. 243–249, 1999, doi: 10.1191/026921599668801945.

[5] E. A. Biddiss and T. T. Chau, "Prosthetics and Orthotics International Upper limb prosthesis use and abandonment : A survey of the last 25 years," *Prosthetics and Orthotics International*, vol. 31, no. 3, pp. 236–257, 2007, doi: 10.1080/03093640600994581.

[6] M. Yamamoto *et al.*, "Cross-sectional International Multicenter Study on Quality of Life and Reasons for Abandonment of Upper Limb Prostheses," *Plastic and Reconstructive Surgery - Global Open*, vol. 7, no. 5, p. e2205, 2019, doi: 10.1097/gox.0000000000002205.

[7] M. Egermann, P. Kasten, and M. Thomsen, "Myoelectric hand prostheses in very young children," *International Orthopaedics*, vol. 33, no. 4, pp. 1101–1105, 2009, doi: 10.1007/s00264-008-0615-y.

[8] J. Oliver, C. Dixon, and C. D. Murray, "Being the parent of a child with limb difference who has been provided with an artificial limb: an interpretative phenomenological analysis," *Disability and Rehabilitation*, vol. 0, no. 0, pp. 1–8, 2018, doi: 10.1080/09638288.2018.1543462.

[9] R. C. Crandall and W. Tomhave, "Pediatric unilateral below-elbow amputees: Retrospective analysis of 34 patients given multiple prosthetic options," *Journal of Pediatric Orthopaedics*, vol. 22, no. 3, pp. 380–383, 2002, doi: 10.1097/01241398-200205000-00023.

[10] M. A. James, A. M. Bagley, K. Brasington, C. Lutz, S. McConnell, and F. Molitor, "Impact of prostheses on function and quality of life for children with unilateral congenital below-the-elbow deficiency," *Journal of Bone and Joint Surgery - Series A*, vol. 88, no. 11, pp. 2356–2365, 2006, doi: 10.2106/JBJS.E.01146.

[11] A. M. R. Agur and M. J. Lee, *Grant's Atlas of Anatomy*, 10th ed. Lippincott Williams and Wilkins, 1999.

[12] T. Feix, J. Romero, H. B. Schmiedmayer, A. M. Dollar, and D. Kragic, "The GRASP Taxonomy of Human Grasp Types," *IEEE Transactions on Human-Machine Systems*, vol. 46, no. 1, pp. 66–77, 2016, doi: 10.1109/THMS.2015.2470657.

[13] I. M. Bullock, J. Z. Zheng, S. de La Rosa, C. Guertler, and A. M. Dollar, "Grasp frequency and usage in daily household and machine shop tasks," *IEEE Transactions on Haptics*, vol. 6, no. 3, pp. 296–308, 2013, doi: 10.1109/TOH.2013.6.

[14] I. Vujaklija, D. Farina, and O. Aszmann, "New developments in prosthetic arm systems," no. July, 2016, doi: 10.2147/ORR.S71468.

[15] "bebionic," 2019. [Online]. Available: https://shop.ottobock.us/Prosthetics/Upper-Limb-Prosthetics/bebionic/c/2888. [Accessed: 28-Feb-2020].

[16] "Touch Solutions." [Online]. Available: https://www.ossur.com/en-us/prosthetics/touch-solutions. [Accessed: 28-Feb-2020].

[17] "Michelangelo Hand," 2019. [Online]. Available: https://shop.ottobock.us/Prosthetics/Upper-Limb-Prosthetics/Michelangelo-Axon-Bus-System/Michelangelo-Hand-AxonHook/Michelangelo-Hand/p/8E500~5R-M. [Accessed: 28-Feb-2020].

[18] "Vincent Systems," 2020. [Online]. Available: https://vincentsystems.de/en/. [Accessed: 28-Feb-2020].

[19] "LUKE Arm Details," 2020. [Online]. Available: https://www.mobiusbionics.com/luke-arm/. [Accessed: 28-Feb-2020].

[20] "Taska Hand." [Online]. Available: https://www.utaharm.com/Taska/. [Accessed: 28-Feb-2020].

[21] C. Castellini *et al.*, "Proceedings of the first workshop on peripheral machine interfaces: Going beyond traditional surface electromyography," *Frontiers in Neurorobotics*, vol. 8, no. AUG, pp. 1–17, 2014, doi: 10.3389/fnbot.2014.00022.

[22] C. Pylatiuk, S. Schulz, and L. Döderlein, "Results of an internet survey of myoelectric prosthetic hand users," *Prosthetics and Orthotics International*, vol. 31, no. 4, pp. 362–370, 2007, doi: 10.1080/03093640601061265.