Development and Testing of a Modular Upper Extremity Exoskeleton for Infants

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Abstract: A passive upper extremity exoskeleton has been developed for people with neuromuscular weakness. The WREX (Wilmington Robotic EXoskeleton) has been used successfully for a number of years by people with disabilities such as muscular dystrophy and arthrogryposis. This paper describes the modification of the WREX to be fitted with infants. The Pediatric WREX Plus (P-WREX+) can selectively assist or resist antigravity arm movements based on the needs of each individual. It consists of a 3-D printed device that can be mounted to a jacket or a chair and allows infants more access to their environment by augmenting anti-gravity arm movement. The target population is infants born with brain injuries and at high risk for significant neuro-motor impairments. The paper describes the development of the device and testing with an infant with arthrogryposis over a 6-month period.

1 INTRODUCTION

Bioengineered devices for the arms have made significant advances in the rehabilitation of adults with nervous system injury. There is a surprising lack of adaptation of these devices for use in pediatric populations. This is especially troubling given the importance of early intervention and rehabilitation for optimal neurological and behavioral development. This paper describes the development of a novel upper extremity orthosis that is based on the WREX, which is a passive upper extremity orthosis.

One version of the WREX, figure 1, is a mechanical linkage that can be attached to a wheelchair and is powered by elastic bands (Haumont 2011, Rahman 2007). The device moves alongside the arm and makes anti-gravity movements effortless. This is particularly useful for people with muscular dystrophy and spinal muscular atrophy where weakness in larger proximal muscles is evident while distal muscles are less affected. The WREX allows them to navigate their hand in front of them and perform activities of daily living. The WREX comes in one size and can be adjusted to accommodate different sized individuals and the number of elastic bands can be changed depending on the weight of the individual.

A second version of the WREX is made for smaller children, figure 2. A 3-D printer is used to fabricate the parts resulting in a lighter and custom fitted device. Some of the children are able to ambulate independently therefore require a body-mounted WREX. We modified a thoracolumabarosacral orthosis (TLSO) commonly used for scoliosis treatment.

The WREX has been used successfully in children older than 2 years of age but has not yet been used in infants. This paper describes the experience of using the P-WREX+ for wear and intervention with an 8-month-old infant with arthrogryposis multiplex congenita (AMC). Infants with AMC are born with joint contractures and muscle tissue fibrosis in more than one region of the body. Typically the biceps and deltoid muscles are weak preventing performance of key activities against gravity.

We wanted to provide this technology in coordination with intervention to advance the exploratory and learning abilities of this infant with special needs. Exoskeletons such as the WREX advance movement and function in older children and adults with neuro-motor impairments (Iwamuro 2008, Hesse 2003).

This study is the first to systematically test the effects of a similar device on reaching ability in an infant with significant arm movement impairments.

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2 P-WREX+ DEVELOPMENT

The WREX is 4 degrees of freedom, 2-link mechanism, fig 2, that supports the weight of the arm for all positions in 3-D space. It is passively actuated by elastic bands placed on the forearm and the upper arm links. A four bar mechanism on the upper arm provides a vertical member at the elbow during the entire vertical excursion. The stiffness of elastic bands, and end points are chosen according to

Figure 1: WREX attached to wheelchair.

The P-WREX+ was scaled down in size to fit a 3-8 month old infant. The jacket was also made smaller and lighter, Fig 3. All the parts of the P-WREX+ were made with ABS plastic. It is inexpensive, lightweight, portable, adaptable, and easy to use. It is fabricated by a small, in-house 3-D printer (Dimension 1200, Stratasys, Eden Prairie, MN) analysis described in (Rahman, 1995). The resulting motion provides identical equilibrium for all position of the arm. This allows an individual to perform activities of daily living such as eating in a gravity-free environment. The number of bands can be varied according to the weight of the subject and

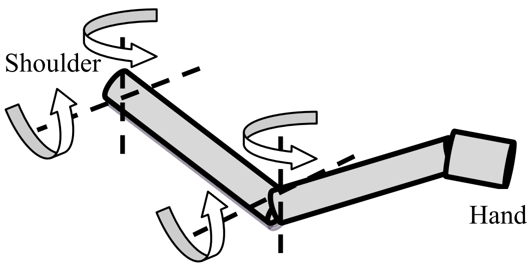

Figure 2: Joint layout of the wrex.

the link lengths can be adjusted for different sized subjects.

Figure 3: p-wrex+.

3 EXPERIMENTAL PROTOCOL

Participant: We followed an 8-month-old infant diagnosed with AMC for a 6-month period. Although he was born with joint contractures, he had functional passive range of motion at all joints of the upper extremities at the time he entered the study. This was the result of early intervention and daily stretching. His muscle strength for raising his upper extremities (shoulder flexion) against gravity while sitting was poor minus. He could perform less than 10 degrees of shoulder flexion against gravity and only partial range of motion with gravity eliminated.

The assessments were video recorded and later coded by trained and reliable (>85% reliability) coders. They recorded times the infant was contacting the object and times he was looking at the object

During the baseline period, the infant did not use the P-WREX+ outside of the brief assessment periods. During the intervention period, the infant wore the P-WREX+ daily for an hour while performing prescribed play activities aimed at promoting reaching and object manipulation abilities. During the post-intervention period, the child kept the P-WREX+ and wore it daily as during the intervention period but he was no longer provided the prescribed play activities while wearing the device

Data Analysis: Results were analyzed via visual inspection of charted data.

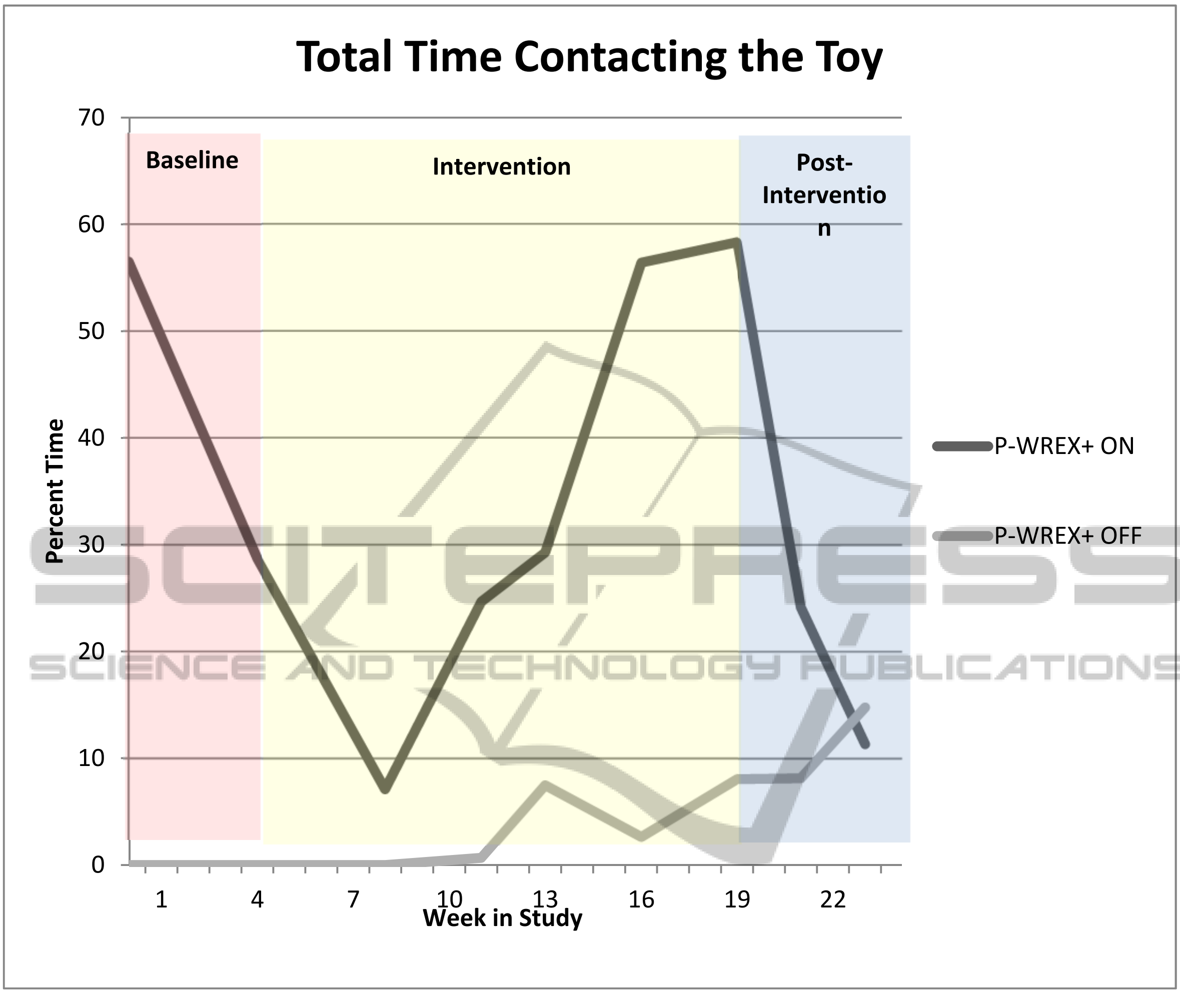

Figure 4: Graph showing the time the toy was contacted by the subject with the WREX.

4 RESULTS

There are several important findings from this preliminary study. First, the infant was able to safely and comfortably wear the P-WREX+ daily, suggesting this and similar devices can successfully be incorporated into the lives of families with infants and young children.

Second, the infant was almost always better able to interact with objects while wearing the P-WREX+. Interaction with objects is important for early language, perceptual-motor, social, and cognitive development and is a precursor for future essential life skills such as dressing and feeding. Therefore, devices like the P-WREX+ may be useful in advancing global development and upper extremity function.

Third, intervention in combination with use of the device was more effective at advancing behavior than was use of the device alone.

This suggests devices like the P-WREX+ have strong potential to advance development and function when paired with play activities prescribed by an early intervention expert.

Finally, the infant showed improved ability to interact with objects, figs 4,5, throughout the study even when he was not wearing the device. This suggests devices like the P-WREX+ are not only successful assistive devices that improve function when worn, but that they may also be successful rehabilitation tools that result in behavioral advances even after they are doffed.

Future goals for this research program include: 1) determining the impact of the P-WREX+ for infants, children, and adults with a variety of

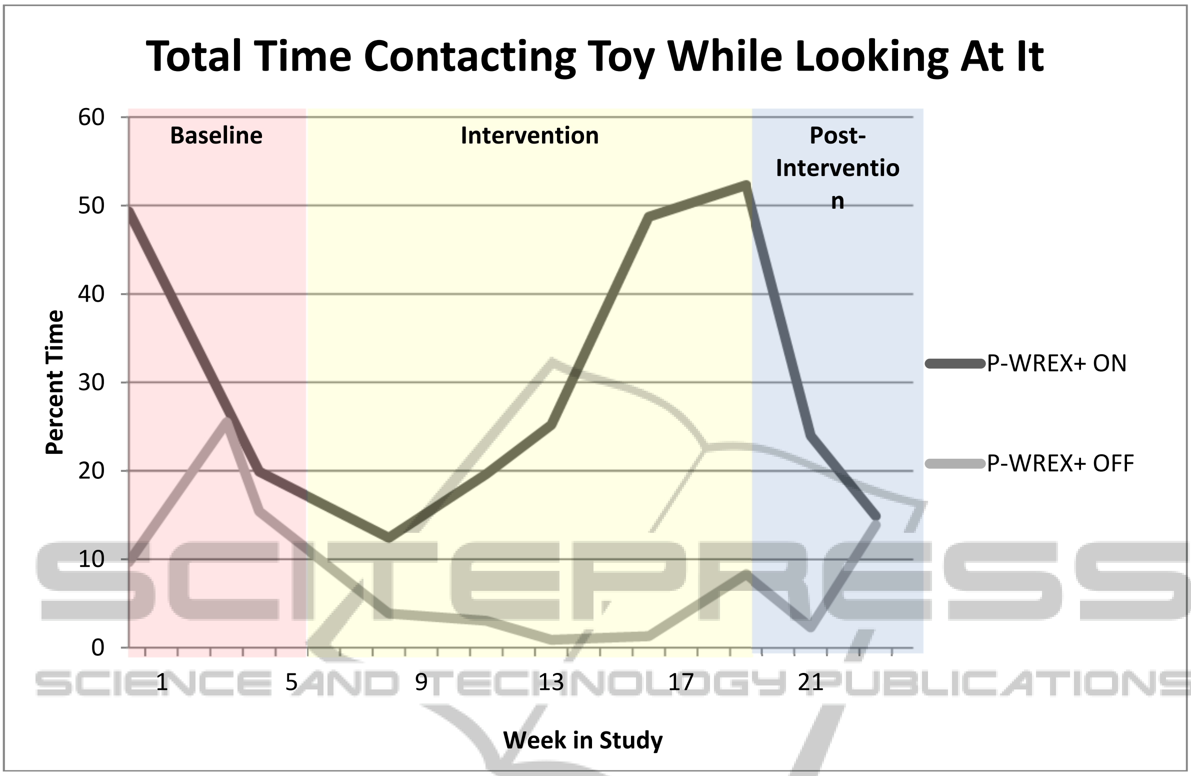

Figure 5: Graph showing the time the toy was contacted while looking at it by the subject with the WREX.

diagnoses impacting arm movement, such as brain injury, brachial plexus palsy, and stroke, and, 2) exploring both low-tech and high-tech future adaptations of the device.

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