

Feasibility and Effectiveness of a Soft Exoskeleton for Pediatric Rehabilitation



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Abstract Exoskeletons have the potential to improve outcomes for rehabilitation clients. For these devices to be effective, rehabilitation professionals and end users must be involved throughout the design process, so the devices meet the broad needs of users. In this article, we present a model to guide the design of rehabilitation devices. This model is user-centered and focuses on users' functional, expressive, aesthetic, and accessibility needs (FEA2) for devices. We then summarize the results of the first studies evaluating the feasibility and effectiveness of the Playskin Lift™ soft exoskeleton for pediatric populations utilized for intervention in the natural environment. The exoskeleton was feasible for daily use by families in the natural environment. For infants and toddlers with physical disabilities, the exoskeleton assisted reaching and play performance within a single session when it was worn and improved independent reaching function and play activity after months of daily intervention with the exoskeleton.

1 Introduction

Children with diagnoses such as arthrogryposis and muscular dystrophy have weakness that can impair their arm function for critical daily tasks [1, 2]. Young children born preterm or with a brain injury also demonstrate arm movement impairments that restrict interaction with objects, limiting children's ability to gather information and learn [3, 4]. Therefore, there are a number of pediatric populations that may benefit from rehabilitation devices aimed at supporting and assisting arm function.

Exoskeletons have been increasingly investigated with adult and adolescent rehabilitation populations [5, 6]. However, until recently, these devices had not been

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studied with very young populations [1, 3, 7]. Furthermore, most of the existing research has been conducted in laboratories or clinics rather than in the natural settings in which clients reside and participate [5, 6]. The purpose of this article is to summarize the results of the first studies evaluating the feasibility and effectiveness of a soft exoskeleton for young pediatric populations utilized in the natural environment. Implementation in the natural environment is especially critical for young children as this is where early interventions are expected to be administered.

2 Material and Methods

2.1 *The Exoskeleton*

The Playskin Lift™ exoskeletal garment was designed by the author's team using the FEA2 user-centered design model that considers the functional, expressive, aesthetic, and accessibility needs of end users [8]. Parents of young children with arm movement impairments reported the need for a device to help children lift their arms for daily activities while also meeting other key needs, including ease of donning/doffing, aesthetics, affordability, and comfort. It was also important that the device not restrict other activities such as rolling and transitioning among positions [8].

The Playskin Lift™ is a passive exoskeletal garment [8]. It is a onesie or shirt that zips in the front and has vinyl tunnels under each arm to hold springs, bundles of steel wire, that provide antigravity assistance at the shoulders (Fig. 1). Level of assistance can be adjusted by selecting a greater number and/or larger diameter of wires. The exoskeleton can be fabricated for less than 30 US dollars in materials following instructions posted at the author's website.

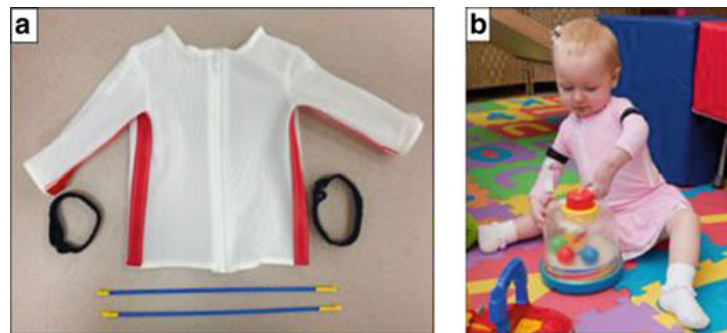


Fig. 1 The Playskin Lift™ exoskeletal garment **a** with vinyl tunnels under each arm for the springs (bottom of the image) and **b** on a child; hook and loop cuffs to be used as needed to maintain spring alignment

2.2 Methods

Feasibility and effectiveness of the Playskin Lift™ were evaluated in two groups of young children. The first group was of 10 infants born preterm and/or with a significant brain injury (PT/BI) [3]. They began the study at about 2 months of age, adjusted for prematurity. The second group was of 17 infants and toddlers with significant arm weakness due to arthrogryposis [1, 7]. They began the study between 6 and 35 months of age. Both groups were evaluated biweekly throughout a 1–2-month baseline (control), a 4-month intervention (with daily, parent-provided home intervention activities with the exoskeleton donned), and a 1-month post-intervention phase. Daily wearing logs and parent perception questionnaires assessed feasibility. A standardized reaching assessment was performed biweekly with and without the device to assess effectiveness for both groups. The arthrogryposis group was also assessed for active range of motion (AROM) and play ability as this group demonstrated limited AROM and play was developmentally appropriate for this older group. Experimenters blind to visit timing and participant details scored all assessments. Hierarchical linear modeling analyzed assistive effects (changes within a session with the exoskeleton donned) and rehabilitative effects (changes in independent performance across time) with $p \leq 0.05$ representing significance.

3 Results

3.1 Feasibility

The Playskin Lift™ exoskeletal garment was feasible for use by parents for daily intervention with infants and toddlers in the natural environment [1, 3]. Parents were asked to use the exoskeleton for intervention 45 min/day each day, skipping days as needed. Parents in the PT/BI group reported wearing times of 44.4 ± 9.3 min/day 3.9 ± 1.7 days/week; parents in the arthrogryposis group 96.8 ± 81.4 min/day 5.8 ± 1.2 days/week. Likert ratings on a scale from 1 to 5 with 5 being the best were positive for all outcomes, including ease of donning (PT/BI: 4.5 ± 0.5 ; arthrogryposis: 4.4 ± 0.4) and doffing (PT/BI: 4.5 ± 0.5 ; arthrogryposis: 4.6 ± 0.4), comfort (PT/BI: 4.3 ± 0.9 ; arthrogryposis: 4.7 ± 0.4), aesthetics (PT/BI: 3.7 ± 1.2 ; arthrogryposis: 3.9 ± 0.7), and restriction of other activities (PT/BI: 3.9 ± 1.2 ; arthrogryposis: 4.2 ± 0.7).

3.2 Assistive Effects

Infants and toddlers showed better reaching performance within sessions with the Playskin Lift™ donned [1, 3]. Infants with PT/BI showed significantly more

bimanual reaching, open-handed grasping, and multimodal (visual-manual) behavior when wearing the exoskeleton [3]. Toddlers with arthrogryposis showed significantly more unimanual and bimanual reaching, open-handed grasping with the palm, visual attention to objects, and multimodal behavior along with increased intensity of activity [1]. Toddlers with arthrogryposis showed better play performance, with significantly more object contacts, lifting of objects, bimanual object manipulation, and multimodal behavior along with increased intensity and variability of the behaviors performed [7].

3.3 *Rehabilitative Effects*

Infants and toddlers showed improved independent reaching performance across time after intervention with the Playskin Lift™ [1, 3]. Infants with PT/BI showed significantly more unimanual and bimanual reaching, open-handed grasping with the palm, attention to objects, and multimodal behavior along with increased intensity of activity [3]. Toddlers with arthrogryposis showed significantly improved AROM for both upper extremities, more unimanual reaching, open-handed grasping with the palm, visual attention to objects, and multimodal behavior along with increased intensity of activity [1]. Toddlers with arthrogryposis had better play performance, with significantly more object contacts, lifting of objects, unimanual object manipulation, and multimodal behavior along with increased intensity and variability of the behaviors performed [7].

4 Conclusion

This work suggests that upper extremity exoskeletons, such as the Playskin Lift™, designed to meet the broad needs of users are feasible for use in intervention programs implemented by parents for very young pediatric populations in the natural environment [1, 3, 7, 8]. Exoskeletons like the Playskin Lift™ can provide more immediate effects on reaching and play abilities (assistive effects when donned) for young children with upper extremity disability [1, 3, 7]. When coupled with effective intervention activities, they can also improve independent AROM, reaching, and play abilities across time [1, 3, 7]. Exoskeletons that improve motor performance for young children may lead to cascading benefits in cognition, language, and social abilities [3, 4]. Key limitations of the Playskin Lift™ for populations over 3 years of age are that it cannot support the weight of longer, heavier arms and it does not allow users to adjust the level of support in real time. Future research should apply the FEA2 design model to develop soft exoskeletons that address these limitations and the needs of older pediatric and adult populations.

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