Skills on Wheels: Development of a Pediatric Upper Extremity Pain Assessment, a Play-based Home Exercise Program, and Best Practices for Wheelchair Propulsion

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Acknowledgments

There are several individuals who I would like to personally thank and shout out for helping me fulfill the goals of this doctoral capstone.

First, I would like to thank my professors/mentors involved with Skills on Wheels, Dr. Chase, Dr. Albright, Dr. Van Antwerp, and Dr. Hull for providing me with guidance in terms of adapting my doctoral capstone to fit the needs that we saw as important during Skills on Wheels. In addition, thank you to one of Skills on Wheels' previous capstone students, Niki Hoseinpour for setting the groundwork with the upper extremity portion of Skills on Wheels.

Second, thank you to Alex Perry for coding and developing the app we utilized in conducting our pediatric pain assessment during Skills on Wheels. Also, a shoutout to Kate Schrader for providing insight related to this doctoral capstone and for connecting me to Alex Perry.

A thank you to my family and friends who've supported me throughout these 3 extra years of OT school. Lastly, I wanted to thank and acknowledge the other Skills on Wheels capstone students, Raegan Hadley and Anna Legue. I also want to thank the rest of the on-campus capstone students for providing me with a memorable last semester of OT school.

Thank you everyone!

Abstract

Skills on Wheels, a program based in Indianapolis, Indiana provides pediatric manual wheelchair users ranging from ages 6 to 17 with the chance to learn essential wheelchair skills important for daily use at home and in the community. The impact that manual wheelchair use has on a participant's upper extremities, which are crucial for a participant's ability to live their lives independently and have the best quality of life when engaging in Activities of Daily Living (ADLs)/Instrumental Activities of Daily Living (IADLs)/play continues to deserve further attention. Given the role the upper extremities have on a participant's daily life, it is vital to examine the research to provide program participants with resources that will help prevent upper extremity pain and injuries in the future. Research supports home exercise programs (HEPS) and best practices with manual wheelchair propulsion to help prevent upper extremity pain as a result of prolonged upper extremity use. This doctoral capstone project aimed to investigate upper extremity kinematics and propulsion ergonomics among manual wheelchair users to provide best practices for participants, understand how Skills on Wheels' current upper extremity HEP could be adapted/replaced to benefit its pediatric population to strengthen upper extremities, and to develop a pediatric-friendly upper extremity pain assessment for Skills on Wheels to provide pertinent upper extremity data to enhance outcomes. Data collection involved measuring range of motion (ROM), grip/pinch strength, receiving caregiver feedback, and a pain assessment to identify benefit of the resources provided for participants. Results highlight the benefits of using a play-based HEP and propulsion resources in maintaining upper extremity health and preventing pain among participants. Pain assessment data provide valuable information related to the upper extremity and pain participants may face engaging in various occupations.

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Introduction

Skills on Wheels, a program affiliated with Indiana University based in Indianapolis, Indiana, was established to empower and enable children who use manual wheelchairs to navigate their surroundings within their communities confidently and fearlessly when maneuvering various life situations (Chase et al., 2024). The community profile of Skills on Wheels encompasses children in Indianapolis and its surrounding areas who use manual wheelchairs between the ages of 6 and 17. This program's participants may have various diagnoses including Spinal Cord Injuries, Spina Bifida, Arthrogryposis, Mitochondrial Disease, and Cerebral Palsy, among others. These children go into a world that has historically not had them in mind regarding accessibility and design. The overarching goal of Skills on Wheels is to enable them to navigate their communities safely and independently, despite the constraints imposed on them by a predominantly ableist society.

Upper extremity data from last year's Skills on Wheels program was collected to shed light on the impact of a home exercise program (HEP) in improving upper extremity outcomes, including strength, and Range of Motion (ROM), as well as identifying pain that may arise in participants due to overuse that occurs with propelling a manual wheelchair (Hoseinpour, 2023). Among people using manual wheelchairs, 71% will report shoulder pain due to daily manual wheelchair use. This is a potential problem among Skills on Wheels participants because the onset of pain can inevitably worsen occupational performance in these children's activities of daily living, functional mobility, play/leisure, and other occupations they engage in (Mason et al., 2020). One aim of Skills on Wheels is to address occupational performance issues relating to the upper extremities as the program progresses by assessing the acquired data and incorporating play-based resources, assessments, exercises, and other tools. These resources will ultimately

aim to reduce and prevent prospective injuries or pain that may develop among participants as the program continues to evolve.

Needs Assessment

In establishing Skills on Wheels as the focus of this doctoral capstone site, a questionnaire-based interview rooted in the community and site profiles of Skills on Wheels to further assess this site's needs and gaps within the literature was created. This involved conducting an initial literature search, thoroughly examining the work of previous doctoral capstone students in the program, and personally observing the program to identify potential barriers for participants and opportunities to improve the program.

For the questionnaire-based interview, questions were developed concerning previously conducted upper extremity research with a professor in Indiana University's Occupational Therapy program, who is also involved as Skills on Wheels' biomechanical-focused researcher. The questionnaire-based interview can be located in Appendix A. Questions were asked in a semi-structured manner concerning biomechanical components of the upper extremity including ROM, muscle strength, contractures/strains/injuries from repetitive use, and what has been done to address these deficits in the past. In addition, given the involvement of previous doctoral capstone students with Skills on Wheels, it was vital to understand their research contributions and identify how it could be expanded upon to further research related to improving upper extremity outcomes for the participants of Skills on Wheels.

Throughout the duration of this doctoral capstone project, from the initial interview to the current stage of completion, adjustments were made to align with the adapting needs and nature of Skills on Wheels. These changes are further discussed in this paper.

Upon reviewing the qualitative results from the interview, subjective observations during participation in the program, and a preliminary search of the literature, various needs were identified to be addressed in this doctoral capstone. The most prevalent themes within the interview addressed the impact of a HEP on the biomechanical component of the upper extremity, adverse effects of upper extremity pain, weakness, and/or strain among participants, and manual wheelchair propulsion as an important component to consider in preventing deficits mentioned above. Regarding subjective observations while on site, the importance of developing a pediatric manual wheelchair users upper extremity pain assessment was evident. Lastly, upon reviewing the limitations that last year's capstone student described, incorporating a method to assess HEP adherence and usability was also deemed important to understand the participants' and their caregivers' interpretations of the HEPs provided. Using these themes obtained from the interview, subjective observations, and data retrieved from the literature – several gaps were identified.

Gap Analysis Statement

Upon completion of the needs assessment, it was determined that factors related to upper extremity functioning in daily life deserved to be addressed. These included addressing upper extremity weakness and manual wheelchair propulsion among participants due to upper extremity pain onset which could subsequently impact functioning in daily life. Weakness and/or pain can further decrease a participant's quality of life and social participation, due to participants having to overcome pain in their upper extremities when performing Activities of Daily Living (ADLs)/Instrumental Activities of Daily Living (IADLs) (Mulroy et al., 2015). In addition, questions largely remain unanswered about assessing upper extremity pain and its impact on occupational performance as it relates to pediatric manual wheelchair users. The

Wheelchair User's Shoulder Pain Index (WUSPI) as well as other reputable upper extremity assessments exist as good indicators of measuring upper extremity pain in daily life. However, limitations arise when conducting these assessments with the pediatric population, specifically among those who use manual wheelchairs. Limitations include irrelevant questions and lack of understanding of the assessments when completed by Skills on Wheels participants. Upper extremity weakness that participants face can lead to fatigue and pain, resulting in impairments with wheelchair propulsion or movement, ultimately impacting upper extremity kinematics and functioning while using a manual wheelchair (Silvestri et al., 2022). Pain and potential injury particularly within the shoulder can appear in manual wheelchair users soon after beginning the use of their wheelchair, with many adult manual wheelchair users experiencing pains within five years of initial wheelchair fitting. Pain could subsequently become tougher to address in the future due to its chronic nature (Silvestri et al., 2022).

The previously mentioned gaps are issues that need to be addressed because early prevention can help decrease the need for invasive surgeries in the future, prevent long-term injuries or pain that may arise, and improve general quality of life (Mulroy et al., 2015). The doctoral capstone student therefore determined where improvements could be made to patient capabilities and outcomes. This was done by reviewing assessments and tools to accurately measure the impact of pain on daily occupation and identifying upper extremity pain and weakness prevention strategies for participants. As previously mentioned, an exercise program originating from last year's Skills on Wheels program had been established for participants; further research was also conducted this year to develop an alternative play-based upper extremity HEP.

Problem Statement and Purpose

Given the information presented within the needs assessment and gap analysis, several purposes for this doctoral capstone were identified based on the problems Skills on Wheels participants face. One purpose of this project was to investigate upper extremity kinematics and propulsion ergonomics among pediatric manual wheelchair users to provide best practices for participants. Further research also explored existing studies on the benefits of manual wheelchair upper extremity exercise programs, to understand how Skills on Wheels' current upper extremity HEP could be adapted or replaced to benefit its pediatric population. Lastly, a pediatric-focused upper extremity pain assessment, similar to the Wheelchair User's Shoulder Pain Index and the Pediatric Adolescent Shoulder Survey, was developed and implemented for Skills on Wheels to further improve outcomes among its participants. The prior purposes aimed to address the primary upper extremity-related problems Skills on Wheels participants face, including the development of deficits/pain resulting from manual wheelchair propulsion, upper extremity strain and weakness, and fatigue and their impact on occupational performance.

Literature Review

A systematic literature review was conducted for this doctoral capstone to analyze several facets of research. This encompassed exploring validated upper extremity pain assessments and their applicability in developing a pediatric-oriented manual wheelchair users' upper extremity pain assessment, an examination of the literature on implementing an alternative Skills on Wheels HEP to meet the needs and abilities of participants, and research conducted on preventive measures for upper extremity pain in manual wheelchair users. This was performed to enhance the overall quality of life of program participants. The primary databases used while gathering evidence were Google Scholar and PubMed. The primary search terms utilized to retrieve pertinent evidence included pediatric wheelchair users, manual wheelchair users, upper

extremity pain, quality of life, shoulder pain, and home exercise program, among others. 16 of the articles were published within the past 10 years, while 1 article was published over 10 years ago. The primary method of obtaining level 1 research was determining the type of study conducted among participants and the level of evidence supported by the study conducted by the researchers. Essentially examining whether it was a pilot study, a randomized control trial, a systematic review, etc. The research reviewed for this doctoral capstone was relevant to the purpose of expanding a former doctoral capstone student's upper extremity HEP, providing methods for preventing upper extremity pain, and creating a pediatric manual wheelchair users pain assessment to improve upper extremity outcomes by identifying upper extremity pain encountered in daily life.

Population Background

It can be assumed that most children early in their lives envision a future where they can become anything they want to be, do anything they aspire to do, and most importantly, live a childhood that is encapsulated by play, security, and free of pain or judgment. However, as with many things in life, this is not the reality for a wide variety of children. Numerous things can impact a child's upbringing as well as their perception of the world around them; including various morbidities that impact daily occupation, adverse child experiences kids may face, occupational injustices surrounding a child, and much more that can hinder this perceived reality (Iwasaki et al., 2014).

A pediatric population that faces adversity includes those who use manual wheelchairs. This population is a diverse cohort of children that includes kids affected by various disabilities that have led to them utilizing a manual wheelchair in their daily lives. Whether part-time or full-time, being a pediatric manual wheelchair user can lead to unique challenges and considerations

due to their age, developmental stages, and social stigma. Many times, these groups of children can achieve almost everything that their peers can. However, they may have to put in more effort and face more daily obstacles compared to those around them.

An issue this population encounters daily that continues to be addressed and still has more work to be done stems from disability rights and the ongoing struggle for those with disabilities to obtain the same opportunities as non-disabled individuals. The disability rights movement had only begun picking up steam in the United States within the past hundred years and throughout the past century, it had steadily made persistent strides of progress. However, it was not until 1990 that a landmark achievement was marked by the passage of the American Disabilities Act (ADA). The ADA is a civil rights law that prohibits discrimination against people with disabilities, deviating from the past when there were no federal regulations to protect people with disabilities. The ADA allows people with disabilities to work freely, be active members of the community, receive public accommodations, and in general have similar liberties as non-disabled people around them (Abrams, 2020). The ADA was a monumental moment in the disability rights movement, and it had profound effects on improving accessibility and fighting discrimination in America. However, to this day the disabled community still faces many inequalities, stigma, and misconceptions in everyday activities. Unsurprisingly, many settings are still inaccessible for disabled people and especially for those who use wheelchairs, primarily because of historical barriers, stigma, and poor design. Children with disabilities in particular have fewer opportunities in school, more barriers to finishing school, and difficulty pursuing higher education compared to their peers (Abrams, 2020). Again, these barriers stem from a world that has largely not provided necessary accommodations for pediatric wheelchair users nor provided them with similar opportunities for success.

Furthermore, physical deficits such as repetitive strain injuries and/or upper extremity weakness leading to pain resulting from manual wheelchair use are significant in manual wheelchair users. This is a problem because of the impact that these deficits can have on occupational engagement among children who use manual wheelchairs, with potential long-term effects if they become chronic as the child gets older. In some cases, upper extremity overuse injuries and pain in wheelchair users can be attributed to the aforementioned barriers described in the previous paragraph. Current literature shows that providing manual wheelchair users with exercise/stretching programs, assessing pain in manual wheelchair users, and encouraging functional, kinematic propulsion may improve outcomes when comparing pre-and post-results after receiving these resources. Assessments such as a pain scale could also measure the impact of these programs on this population, indicating whether they are beneficial for their quality of life and self-efficacy.

The Impact of Upper Extremity Pain on Daily Life

Upper extremity pain resulting from consistent manual wheelchair use can be much more debilitating than non-disabled individuals may believe. A study conducted by Silvestri et al., in 2022 examined the effects of chronic shoulder pain on participants' ability to engage in occupations. The researchers used semi-structured interviews to obtain lived experience information from four participants who had all suffered spinal cord injuries. A thematic analysis was performed to determine similar themes among participants. Anger, fear, loss, the participant's intrinsic factors, extrinsic factors, what lies ahead, and resilience were identified as shared themes.

All the participants indicated that upper extremity pain impacted their occupational engagement in ADLs and IADLs among other activities. Each participant shared an intrinsic

motivator or quote that kept them optimistic about themselves and their future, indicating that upper extremity pain would not inhibit them from gaining and maintaining independence. Third, participants indicated that despite upper extremity pain and its impact, they still found ways to remain independent and only relied on family and friends if needed. All of them mentioned that these supporters were consistently there to help motivate and support them with whatever they may need. Regarding what lies ahead, the participants all worry about how shoulder pain could worsen and remain chronic to the point where it would reduce their functional independence and occupational participation. The participants also stated that through therapy, they have worked on wheelchair modifications and obtaining equipment to help reduce upper extremity strain injuries. With the incorporation of therapy, this most likely included therapeutic exercise/activity, recommendations on modifications, etc. Lastly, resilience was a common theme among participants since given what many had overcome, upper extremity pain was just another barrier they would have to go through. It is evident that upper extremity pain has a large mental health component and can be taxing to manual wheelchair users. Regarding Skills on Wheels participants, limiting upper extremity weakness and pain through a variety of methods is important as noted here.

Wheelchair Propulsion, Best Practices, and The Impact on the Upper Extremity

When using a manual wheelchair there are many factors one must consider to maintain functional mobility - one factor being how one propels themselves using their wheelchair. To a non-disabled individual, the way one maneuvers in their wheelchair may not be considered as important, and many may question whether it has a significant influence kinematically. Per an Occupational Therapist with Riley Children's Hospital, children (many being Skills on Wheels participants) fitted for a custom manual wheelchair seldom receive any further instruction or

training on how to best propel themselves in their wheelchairs. There is also a lack of research surrounding manual wheelchair propulsion and the pediatric population. Providing an understanding of best practices for propelling oneself in a wheelchair is crucial to improving long-term outcomes among Skills on Wheels participants.

Children upon being fitted for a manual wheelchair often do not receive any formal training on how to propel themselves effectively and safely in their wheelchair (Dysterheft et al., 2015). As described by Dysterheft et al, a lack of awareness or training in proper wheelchair propulsion techniques in children can lead to an increased risk of developing an injury because of the way they propel. This study examined the impact of an instructional video, and feedback from researchers on propulsion kinematics among a group of 10 pediatric manual wheelchair users to see if educational training would impact their propulsion technique after receiving the intervention. The video, commonly used for adult manual wheelchair users provided methods on increasing contact angle with wheelchair handrims while reducing stroke frequency and peak force on handrims. After receiving the intervention, through the completion of self-propelled carpet and tile trials by participants, and statistical analyses performed by researchers, it was determined that significant improvements were undergone for increased contact angle and reduced stroke frequency during propulsion. Researchers also saw significant increases in peak force on handrims which was attributed to increased velocity while participants propelled their wheelchairs upon receiving the intervention.

A study conducted by Kwarciak et al., in 2012 examined how upper extremity biomechanics among a group of manual wheelchair users are impacted by different propulsion patterns. For the study, researchers had participants propel themselves on a level treadmill, utilizing the 4 most common propulsion techniques - semicircular (SC), pump/arc (P), double

loop (DL), and single loop (SL) stroke patterns. The SC pattern is typically used among experienced wheelchair users and the P pattern is used among inexperienced wheelchair users. The participants in this study largely resorted to using a DL pattern, with more than half of the participants utilizing this pattern on a regular functional basis. To measure the impact of one's propulsion pattern on upper extremity handrim biomechanics, upper limb electromyography (EMG) and measurements taken from a wheelchair wheel were used to compare stroke patterns among participants. To analyze statistical impact of the methods undertaken, a one-way ANOVA was performed. It was deduced that both the SC and the DL propulsion patterns were best for upper extremity biomechanics among participants when propelling oneself functionally. The SC pattern specifically produced larger contact angles with wheelchair handrims for participants and lowest peak force produced among all 4 propulsion patters. A similar study performed by Slowik et al., in 2016 using musculoskeletal modeling and forward dynamics simulations examined how four different propulsion hand patterns (arc, single loop, double loop, semicircular) impacted upper extremity muscle demands. They found that among the four hand patterns, the double loop and SC patterns demonstrated the most favorable results in terms of power and kinematics. The double loop pattern did not require a lot of muscle power during the full cycle and recovery phases of propulsion. Meanwhile, the SC pattern required the 2nd lowest muscle power exerted during the entire cycle of propulsion. Meaning, participants of this study exerted the second least amount of force with manual wheelchair propulsion. In addition, the SC pattern demonstrated muscle power exerted that was evenly distributed between the muscles examined in this study indicating there were no significant variations between the muscles that are responsible for propulsion.

Relevant to the previous article discussed, different research measured the effects of how physical and occupational therapy could improve general upper extremity functioning along with enhance daily activity participation among children. Targeted therapy services provided to participants by each occupational/physical therapist played a role in impacting several variables including the child's type and size of propulsion pattern, their shoulder kinematics, and musculotendon excursion. This 7-week long longitudinal study was conducted among ten 6–17-year-old participants while they attended a summer camp for children with physical disabilities. Each participant was assessed at the beginning, middle, and end of the summer camp. Assessment of the mentioned variables was conducted using a self-developed markerless wheelchair propulsion assessment, the Shriners Hospital Upper Extremity Evaluation (SHUEE), and the Wheelchair Propulsion Test (WPT). The markerless wheelchair propulsion assessment provides therapists with the means to retrieve quantitative data that would enable them to track the progress of patients who use wheelchairs - assessing speed, propulsion pattern, and cadence. This assessment required participants to go through twenty propulsion cycles on a roller platform as well as propel themselves ten meters within a gym at the camp. After the conclusion of the study, it was found that musculotendon excursion, shoulder kinematics, and propulsion pattern were impacted in six of ten participants who demonstrated changes after undergoing therapy. Regarding propulsion patterns and change from the first week, these six participants eventually favored the trunk lean style of propulsion which involves leaning one's upper body forward (Rammer et al., 2019). This type of style is associated with better upper extremity outcomes in the short term, by reducing stress on the upper extremity joints during propulsion – by incorporating a "smoother" semicircular propulsion pattern. Within adults, the semicircular pattern has been correlated with reduced injury risk while allowing for greater force and

propulsion angle produced during each cycle (Slavens et al., 2015). This pattern and its benefit deserve attention despite proportionally different physical builds between adults and children. The study by Rammer et al., also examined how stretching could be beneficial for participants, demonstrating that stretching had a direct impact on kinematic response and was correlated with increased kinematic ROM. This is important because as a result, stretching could contribute to "larger and smoother propulsion patterns" because of an increase in ROM and flexibility (Rammer et al., 2019). Kinematic propulsion patterns and encouraging stretching are shown to have short-term benefits by improving wheelchair propulsion kinematics, potentially resulting in better outcomes with one's perceived pain from manual wheelchair use.

Several studies examine the impact that manual wheelchair use has on the upper extremity pathology of children. 7-26% of pediatric manual wheelchair users who have suffered spinal cord injuries have reported shoulder pain with the number only increasing in incidence into adulthood, reaching up to half of all manual wheelchair users. An increase in the number of individuals who face upper extremity pain as adults correlates with repetitive propulsion subsequently leading to chronic pain (Leonardis et al., 2022). The incidence of shoulder pain increases with particular shoulder joint movements as found in this study above, indicating that increased glenohumeral abduction and scapular downward rotation during propulsion is associated with subacromial impingement impacting the rotator cuff. This study was conducted on 17 manual wheelchair users with ages ranging from 10 to 30 years old. Poor upper extremity outcomes can be associated with repetitive glenohumeral abduction and scapular downward rotation movements during propulsion, with higher prevalence among individuals who began using manual wheelchairs as children. Providing participants with a way to be cognizant of this and to favor more kinematic movement could help benefit long-term outcomes. Another study

conducted in 2015 among 14 pediatric manual wheelchair users with spinal cord injury by Slavens et al., indicated that the glenohumeral joint (shoulder flexion/extension movement) is primarily responsible for the initiation/termination of propulsion in a manual wheelchair. It was found that compared to regular propulsion of manual wheelchairs, more force and demand are required when initiating or terminating movement of the wheelchair with the wrist, elbow, and glenohumeral joints all requiring more joint force and moment. In addition, initiation of the wheelchair proved to be most taxing overall on the upper body with it requiring the most demand on ROM in upper body joints. The most demanding task during the propulsion cycle was shown to be flexion movements which were required most in these 3 joints to initiate the movement of the wheelchair. Lastly, this study examined the four most common propulsion methods with the SC and P methods being examined; tentative findings deduced that pediatric wheelchair users may benefit from using different/a variety of propulsion techniques than adults to limit the risk of pain developing as they age.

Can Exercise Improve Outcomes Relating to Upper Extremity Pain/Weakness?

A HEP was first implemented last year within Skills on Wheels. This program was introduced by a previous doctoral capstone student with a focus on providing upper extremity therapeutic exercise intervention. This involved the development of tailored or generalized exercise programs for participants compared to a control group who received no exercise intervention. Exercises were to be completed at home during the 5-week duration of the program. Of the participants who received exercises, improvements in hand grip and pinch strength were demonstrated. However, overall, when examining participants' upper extremity ROM upon program completion, no notable increases were observed across the three groups. Some participants also demonstrated a decrease in ROM completing home exercises compared to the

control group (Hoseinpour, 2023). Given the results of this exercise program, adaptations to the program itself or an alternative exercise program should be considered to bolster strengthening outcomes for upper extremity muscles involved in propulsion.

Maintaining Skills on Wheels' current HEP while considering an alternative is important for improving outcomes and allowing for greater inclusivity for the participants of this program. Occupational therapy emphasizes play-based intervention or meaningful activity when approaching clients holistically. A systematic review conducted by Weinstock-Zlotnick and Mehta in 2018 assessed the impact of play-based intervention among participants receiving hand therapy. Included were 13 studies total for this review; upon examining the studies and their impact, preliminary evidence of the assessed studies indicated a positive effect for the use of play-based intervention in participants as a means for strengthening the upper extremities. A couple of the assessed studies also included play-based intervention in conjunction with an upper extremity strengthening regimen, displaying benefits for both used in tandem. This information indicates the potential benefit of including alternative play-based exercise options as a means to improve upper extremity outcomes in participants while also maintaining therapeutic exercise as an option for participants.

Manual wheelchair users are susceptible to shoulder instability due to overuse and constant stress placed on their upper extremities from wheelchair propulsion, among other tasks (Mason et al., 2015). Glenohumeral instability, otherwise known as shoulder instability, is a pathology that many manual wheelchair users may face because of their functional circumstances. This means that the humeral head that's aligned with the glenoid fossa no longer maintains a normal alignment during various shoulder movements. This is a pathology that can occur with prolonged manual wheelchair use and is one that could be addressed and potentially

prevented through exercise. Shoulder proprioceptive exercise/stretching exists as a potential protective mechanism in reducing the predisposition of shoulder injury. It has been shown that by incorporating this method of exercise/stretching, one can increase glenohumeral joint mobility and stability while also strengthening surrounding rotator cuff muscles (Lv et al., 2022). Closed chain exercises are the most commonly performed proprioceptive exercises; including these within the new play-based Skills on Wheels HEP could provide benefits for long-term shoulder outcomes if adherence is maintained. Long-term adherence is recommended due to a cumulative impact when performing proprioceptive exercises, with the potential of a "dramatic…" increase in shoulder stability (Ly et al., 2022).

A 3-year long prospective cohort study conducted by Mulroy et al., in 2015 measuring shoulder joint pain in manual wheelchair users with paraplegia found that 39.8% of the total participants developed shoulder pain. The new onset of shoulder pain was determined to be higher in individuals who reported lower activity levels, with baseline maximal isometric torque in shoulder complex muscles being 10% to 15% lower in those who suffered pain. Shoulder pain was also implicated in individuals who had weak shoulder adductor muscles. Essentially indicating that strength/force was lower during isometric (static) muscle contraction, showing participants with weaker muscles and lower strength experienced greater incidence of pain. This information provides benefits for using exercise/strengthening as a preventative measure of shoulder pain in Skills on Wheels participants. Providing a strengthening protocol can be beneficial in bolstering the muscles most responsible for initiation, propulsion, and termination of wheelchair use to improve/prevent outcomes related to upper extremity pain/weakness. A pilot study conducted by O'Connell et al., in 1995 recruited 6 pediatric wheelchair users with either spina bifida or cerebral palsy to partake in a progressive, 8-week strength training program

intended to improve functional mobility through strengthening muscles responsible for wheelchair propulsion. Exercises included many currently provided by Skills on Wheels such as shoulder flexion/extension/abduction, shoulder internal/external rotation, elbow flexion/extension, and shoulder flexion/extension through bench pressing. Participants underwent strengthening 3 times a week during scheduled physical therapy sessions. Upon completion of the posttest, compared to pretest results in both the 12-minute endurance propulsion test and the 50-meter dash, improvements were undergone. Statistically significant improvements were made with the 12-minute endurance test indicating resistance training could have helped lead to improvements in these tests among participants.

The Benefit of Assessment

There are several assessments that exist to measure upper extremity function, pain, and outcomes. One of these, The Wheelchair User's Shoulder Pain Index (WUSPI) assesses pain faced in the daily lives of adult wheelchair users. The WUSPI, created in 1995 is a self-report questionnaire that requires individuals to rate their upper extremity pain level performing various ADLs/ IADLs on a 10-kcm visual analog scale (Harvey and Glinsky, 2019). A measurement is then taken for each of the fifteen self-reported responses and added to determine the pain level out of a total of 150 centimeters. The WUSPI is a good indicator of representing pain with associated ADLs/IADLs of an individual who uses a wheelchair in their daily lives. However, limitations do exist with displaying the type of pain experienced and how often the pain is experienced (Harvey and Glinsky, 2019). Currently, there is no widely known pediatric manual wheelchair users upper extremity pain assessment that exists, and this proved to be a limitation during Skills on Wheels last year while administering the WUSPI. Providing an age-appropriate tool would be beneficial in providing more reliable data with improved validity and applicability,

while potentially providing advances in treatment (Edmonds et al., 2017). Given the age of the participants in Skills on Wheels, many are part of a different target population and many of the questions presented in the WUSPI were not relevant.

One upper extremity pediatric pain assessment that Skills on Wheels could derive questions from to tailor to its population is the Pediatric/Adolescent Shoulder Survey (PASS). The PASS was recently developed for the main purpose of having a relevant pain assessment that targets the pediatric population, with insight from pediatric orthopedic surgeons and an institutional review board in its development. The PASS demonstrated statistically significant differences when operative interventions were undergone for the pediatric population that trialed this pain index, indicating good reliability for the use of the assessment in providing whether there was a positive impact exhibited within the PASS before and after the intervention was provided (Edmonds et al., 2017). The PASS provides a reliable assessment to measure pain associated with upper extremity outcomes, however, does not provide the best benefit as an assessment to use to measure upper extremity pain for pediatric manual wheelchair users given it is a generalized assessment. Adapting the PASS and WUSPI to better fit the needs of Skills on Wheels participants would provide benefits in addressing and understanding the pain faced by participants, ultimately aiming to improve long-term outcomes for Skills on Wheels participants.

Driving Theory

This doctoral capstone project is rooted in the biomechanical frame of reference. The biomechanical frame of reference pertains to an individual’s ROM while they engage in various occupations; with factors such as muscle strength, endurance, and one’s capacity for movement having an impact on engagement (McMillan, 2016). Upper extremity data from last year's Skills on Wheels program indicates ROM and muscle tone may be impacted due to repetitive strain

injuries, upper extremity weakness, and pain (Hoseinpour, 2023). For wheelchair users, upper extremity deficits ultimately inhibit individuals from fully engaging in occupations in the context of their environments. This frame of reference is appropriate for guiding this doctoral capstone because it intends to “prevent deterioration and maintain existing movement for occupational performance”, “restore movement for occupational performance”, and “compensate/adapt for loss of movement in occupational performance” (McMillan, 2016). This frame of reference and its principles are appropriate because relevant to this doctoral capstone, it enables the continuation of the established HEP while creating a play-based HEP to fit the needs of this population best to enhance occupational performance. In addition, the creation of a propulsion infographic to educate both participants and caregivers aims to prevent worse outcomes for participants while providing best practices on how one should propel themselves in their wheelchair. Lastly, the creation of an objective pain assessment tool would help this population in the short and long term by providing data that indicates when and where upper extremity pain is implicated during occupational engagement.

Capstone Plan & Process

Project Plan

This doctoral capstone emphasized the upper extremity and its role in daily use among Skills on Wheels participants. The student considered the role of occupation and volition among children in creating a new upper extremity HEP, with the goal being to maintain adherence to exercise by incorporating play, the prime occupation children engage in. This new HEP was compared to the program's previously created therapeutic exercise HEP, created by a former doctoral capstone student with Skills on Wheels to assess if there were any statistical impacts found comparing the two HEP’s. Exercises incorporated into the play-based HEP were derived

through collaboration, a search of the literature, and knowledge obtained from previous experiences. The student then examined the literature to determine best practices concerning propulsion methods for a pediatric manual wheelchair user; incorporating findings into a pediatric friendly infographic and video attachment for children and caregivers to reference to ensure kinematic propulsion. Resources were provided to participants to fill the gap they had faced previously in learning how to use their manual wheelchairs by providing corroborated means to propel themselves, aiming to bolster long-term upper extremity outcomes. There still largely remains a lack of propulsion research among the pediatric manual wheelchair population. In addition, a PowerPoint was provided to caregivers to promote buy-in among their children to support adherence to exercises and kinematic propulsion during the duration of Skills on Wheels and beyond. Caregivers received education on why the previously mentioned variables are important for maintaining upper extremity joint integrity. The student also evaluated various upper extremity pain assessments to formulate a pediatric manual wheelchair users pain assessment for participants to complete during Skills on Wheels assessment days. Student volunteers administered the assessment via information provided in participant binders describing the assessment and how to accurately complete it with participants. The pain assessment was completed on an app created for Skills on Wheels, providing relevant information to assess pain during functional movement and activity.

This was all developed through the completion of an initial Student Learning Plan described below in **Table 1**. The Student Learning Plan encompasses both the primary project goals and each goal's objectives, identifying how the student will achieve project goals for fulfillment and completion of this capstone project. As mentioned previously in the paper, changes had been made after the completion of the initial plan to the capstone itself to adapt to

the newfound needs of participants of the program. These changes are reflected in the below plan.

Goals and Objectives

Table 1: *List of project goals and student learning objectives designed by the doctoral capstone student for the overall Doctoral Capstone Experience that aligns with Indiana University Doctor of Occupational Therapy (OTD) program curriculum*

Project Goal 1: The student will demonstrate the ability to analyze existing data in order to design, develop, and validate a formal pediatric upper extremity manual wheelchair users pain assessment tool to be used to determine occupational performance challenges in Skills on Wheels participants.	**Project Goal 2:** The student will demonstrate the ability to appropriately administer an established HEP and biomechanical assessments, maintaining consistency to ensure validity with previous years' administration and scoring to provide data, intentionally comparing findings to previous sessions to determine improvements within participants.	**Project Goal 3:** The student will demonstrate ability to develop an appropriate educational tool to provide to participants, caregivers, and volunteers to help bolster upper extremity outcomes in participants and prevent long-term upper extremity pain.
Objective 1: The student will research various upper extremity-related assessments to understand pertinent components relevant to applying to an upper extremity pain assessment.	**Objective 1:** The student will demonstrate research-oriented skills by delving into upper extremity HEP research from previous years in order to evaluate a potential impact arising from adherence to an HEP to determine its benefit to the program.	**Objective 1:** The student will develop an educational wheelchair propulsion infographic and video to provide to caregivers, participants, and volunteers.
Objective 2: The student will explore aspects of occupational performance relevant to the pediatric wheelchair population to assist with developing a questionnaire applicable	**Objective 2:** The student will determine potential methods by diving into research that could assist in creating a new play-based HEP to provide volitional upper extremity	**Objective 2:** The student will provide in-person training to caregivers to further their understanding of best practices with manual wheelchair propulsion

to Skills on Wheels participants.	exercises for Skills on Wheels participants to complete.	
Objective 3: The student will understand the benefit of developing an upper extremity pain assessment for pediatric wheelchair users and its impact improving occupational performance and functional outcomes related to occupational therapy within Skills on Wheels participants.	**Objective 3:** The student will successfully administer biomechanical assessments, with appropriate modifications if needed to Skills on Wheels participants, assessing pre- and post-program biomechanical measurements (ROM, grip/pinch) to measure the impact of the HEP and program participation with the biomechanical measurements.	**Objective 3:** The student will provide in-person training to student volunteers to further their understanding of best practices with manual wheelchair propulsion.

Project Process

A tentative outline the student followed for ensuring sustainment with the completion of the project process is below:

Weeks 1-2: Project Initiation, Review of the Program and its Needs, and Refining Literature Review
Weeks 3-4: Continuation/Completion of Refinement of Literature Review
Weeks 5-6: Assessment Refinement, BUE HEP, and Propulsion Infographic Creation
Weeks 7-8: Beginning Revising and Adding to Capstone Paper
Weeks 9-10: Project Plan and Process of Capstone Paper, Preparation for first Skills on Wheels Session, Ensuring Sound Project Implementation

Weeks 11-12: Preparation for first Skills on Wheels session, Figuring out the flow for the UE portion of Skills on Wheels
Weeks 13-14: Obtaining and Understanding Results from 1st session, Completion of Capstone Paper

Upon initial completion of the doctoral capstone project, through meetings with the site mentor and the faculty mentor, adaptations to the current HEP to best fit the needs of the participants were planned. Necessary changes were also going to be implemented by addressing the limitations described by the previous doctoral capstone students HEP. In addition, an upper extremity pain assessment was to be created that would be utilized in place of the WUSPI that was used during Skills on Wheels last year.

As the process continued into the capstone, the capstone student determined that there was a need to incorporate a volitional, play-based HEP for Skills on Wheels participants. This was determined with assistance from IU OT faculty, deviating from an initial plan of further adapting the current therapeutic exercise HEP. This HEP was created with the described limitations provided by the previous capstone student in mind and to be used instead of just adapting the previous HEP. This was done because the main occupation a child engages in is play and allowing program participants to strengthen their upper extremities while engaging in this volitional task was deemed important. Creating a volitional HEP was also done to determine if a limitation of last year's HEP could be reduced, this limitation being adherence to exercise. Play-based activities were brainstormed between the capstone student and other capstone students on site, in addition to a search of the literature to find appropriate activities for kids who use wheelchairs. Participants receiving a play-based HEP received various items including a zoomball kit, a mitt and catch game, Legos, and therapeutic strengthening putty, among other

items. The HEP was formatted similarly to the previous capstone student's HEP, while also being mindful of last year's limitations. Last year, shoulder overuse was correlated with participants' use of the HEP and it was deemed important to minimize this from occurring with the use of the new HEP; this year the capstone student decided to incorporate fewer shoulder exercises while also emphasizing a sufficient number of intrinsic hand-strengthening exercises. Hand strengthening through the use of therapeutic strengthening putty in last year's HEP was shown to improve pinch and grip strength from the first assessment to the last assessment among participants who were assigned to the then, new therapeutic exercise HEP. Hand-strengthening included various play options for participants receiving this HEP to choose from. Participants were then to be randomly selected into either the play-based HEP group or last year's therapeutic exercise HEP group to measure the impacts between these two HEPs upon participants' completion of Skills on Wheels.

The new pain assessment was created to allow for a pediatric-friendly assessment tool that program participants could complete without needing assistance from their caregivers. This was done due to noticeable confusion seen among participants who completed the WUSPI last year, with many of the results derived from the WUSPI being direct caregiver responses and not from the participants themselves. The WUSPI is a pain index that is specifically tailored for adults thus making verbiage confusing for participants as well as including nonapplicable questions for many participants. The pediatric-friendly pain assessment took homage to the PASS and the WUSPI, adapting it to create an authentic program-specific tool that catered to the participants of Skills on Wheels. This assessment can be found in Appendix G. In addition to providing a pediatric-friendly pain assessment, an app was created for children to use to allow for easier and more engaging completion of the questionnaire as opposed to the WUSPI last year

which was distributed via pen and paper. The app was created with the assistance of an outside party referenced in the acknowledgments who developed the app to fit the needs of the assessment.

A new propulsion infographic was created for caregivers, participants, and volunteers to provide education on best practices when propelling one's manual wheelchair. This was deemed necessary as described in last year's doctoral capstone student's paper and upon gaining an understanding that many pediatric manual wheelchair users do not receive viable education on how to propel themselves in their wheelchairs. As mentioned previously, this information was provided by a Riley Children's Hospital Occupational Therapist who helps with fitting children into their new manual wheelchairs. This propulsion infographic provided a video with a description of how to propel oneself in a wheelchair in addition to written resources that incorporated best practices. This infographic can be found in Appendix F.

Lastly, presentations were given to both caregivers and program volunteers. The presentation given to caregivers was provided on the first day of Skills on Wheels in Caregiver Corner. This presentation consisted of providing caregivers with corroborated findings that supported propulsions methods described earlier for their child's use, in addition to providing the benefits of their children adhering to an upper extremity exercise program. This presentation was provided to increase buy-in among caregivers, potentially allowing for increased adherence to the HEP their child utilizes as well as providing an understanding of why propulsion kinematics are important for their child while they use their wheelchair. Lastly, program volunteers (wheelchair skills personnel) received education through the aforementioned infographic and an in-person demonstration on proper propulsion kinematics. This was done to allow these volunteers to gain an understanding of how their assigned participant should best propel

themselves in their wheelchair, with the intention being for volunteers to enforce best practices regarding propelling oneself in a wheelchair.

Project Implementation

Implementing this doctoral capstone took planning on behalf of myself, fellow Skills on Wheels doctoral capstone students, and Skills on Wheels' Upper Extremity faculty mentor. To ensure sustainability and flow were maintained, instruction was provided to student volunteers of Skills on Wheels both before and during the actual implementation of the capstone on the program's first and last sessions.

Upper Extremity Volunteer Preparation

The doctoral capstone student before Skills on Wheels' first program session had to ensure student volunteers assisting with the completion of the doctoral capstone student's upper extremity research were competent with a few upper extremity-related components. First, the student collaborated with Skills on Wheels' volunteer coordinator to discuss incorporating upper extremity-related training into their general wheelchair skills training. Discussions regarding the allocation of volunteers to the upper extremity research team were also had, with volunteers who indicated interest through a volunteer interest form being chosen to be a part of the team. The doctoral capstone student included training to ensure upper extremity student volunteers understood the best practices for how participants should propel themselves in a manual wheelchair and a review of how to utilize the instruments used on the first and last days of the program. Volunteers who received training on propulsion techniques included 1st year OT students along with each of Skills on Wheels' skills trainers, who all received in-person, visual training. Meanwhile, volunteers who received training on how to use the instruments included

student volunteers who were interested in joining the Skills on Wheels upper extremity team. Instruments students were required to be trained with included goniometers, digital dynamometers, and digital pinchometers. A separate online training module encompassing the functionality of these instruments was created by the doctoral capstone student and was then distributed to the upper extremity team for review in the weeks leading up to Skills on Wheels. This training was aimed at ensuring comfortability with conducting measurements and distributing the assessment during the first and last days of the program.

First and last day of Skills on Wheels

The first day of Skills on Wheels was the primary day where upper extremity research was implemented. On the first and last day of the program, before the arrival of participants, the doctoral capstone student met with the upper extremity team and provided the digital dynamometers and pinchometers, as well as goniometers. These were provided with the upper extremity strength/ROM assessment document that was to be completed with each Skills on Wheels participant. This assessment document can be found in Appendix D. In addition, materials were reviewed again with volunteers to ensure comfortability with taking measurements on participants. Skills on Wheels participants were recruited to participate in the program with the assistance of a fellow Skills on Wheels doctoral capstone student. As an upper extremity Skills on Wheels doctoral capstone student, recruitment of program participants was not something that was of focus concerning project implementation. Initially, a total of 22 participants were originally recruited to participate in Skills on Wheels, respectfully, 16 of the 22 participants showed up on the first date of Skills on Wheels. As previously mentioned, the first day was when most upper extremity research was implemented and to ensure reliability with the completion of this doctoral capstone, participants who showed up on ensuing dates were

excluded from the study. Exclusion occurred due to them not undergoing upper extremity assessment protocols in addition to participants and caregivers not receiving proper training to be competent with allocated HEPs and manual wheelchair propulsion. These 16 participants underwent ROM and strength testing conducted by the upper extremity research team, with each participant's information documented on a pre-assessment form. Upon completing this, the doctoral capstone student then completed a presentation overviewing manual wheelchair-based propulsion and the two HEPs with participants' caregivers. This in addition to program materials contained within the HEPs was provided to caregivers. This was done to ensure buy-in among caregivers promoting the completion of the HEPs and to provide caregivers with an understanding of the importance of the upper extremities in daily manual wheelchair use. After 5 weeks, as previously mentioned, ROM and strength testing was again undergone with a post-assessment ROM/strength document.

Project Evaluation & Results

Data during the first and last program sessions were collected similarly. Similar to last year's program, upper extremity data was collected on both a pre- and post-assessment document. As mentioned previously, this data included measuring participants' grip and lateral/key pinch strength and ROM. ROM data included assessing shoulder, elbow, forearm, and wrist ROM's. ROM and strength data was determined to provide a positive difference if ROM increased for the majority of joint measurements taken. For instance, if ROM increased after 5 weeks with bilateral shoulder forward flexion, extension, and abduction but not bilateral shoulder external rotation nor internal rotation, this was still deemed a positive difference since net difference supported ROM increases in the shoulder. The same process was undergone with measuring a positive difference with grip and pinch strength. In addition to this, the pediatric-

friendly upper extremity pain assessment tool was also utilized between volunteers and participants to assess potential upper extremity pain at the onset of the program. Measurements were undergone during the beginning of the program, with assistance from Skills on Wheels' lead upper extremity researcher and the rest of the upper extremity team. The pain assessment was either completed immediately after measurements were undergone or completed concurrently during measurements by Skills on Wheels skills trainers who received background on the assessment's importance. This data was collected through an app made specifically for this assessment; data was subsequently stored in an Excel sheet. Lastly, a survey assessing the benefit of the upper extremity materials provided to caregivers was completed by caregivers upon completion of the program, contributing to post-assessment results.

Pre-Assessment Results

On the first day of the program, a total of 16 participants were present and formally assessed for their ROM and strength testing. Pre- and post-assessment results can be found adjacent to one another separated by participant ID numbers in Appendix E. Regarding the allocation of HEPs to participants, each participant was randomly selected to be in either the play-based HEP or the therapeutic exercise HEP before the first program session. Unlike last year, participants' upper extremity measurements did not factor into which HEP they received. Both of these HEPs are found in Appendix B and C. There was a total of 7 participants allocated to the Play-based HEP and 9 to the therapeutic exercise HEP. Participants in the play-based HEP were instructed to complete exercises for at least 5 to 10 minutes, increasing or decreasing their length and intensity of exercise to fit the just-right challenge. Participants in the therapeutic exercise HEP were instructed similarly to last year, to complete the HEP once a day, for 10 – 15

repetitions per exercise. The pediatric-friendly upper extremity pain assessment was administered to 16 participants on the first day.

Post-Assessment Results

On the last day of the program, a total of 14 participants were present and formally assessed. Participants who showed up on ensuing dates but who were not present for the first assessment date were not included in the data and regardless of attendance status on the last date, were not assessed. ROM and strength testing was conducted with these 14 participants who were given either the play-based HEP or the therapeutic exercise HEP. Post-assessment results for participants 7 and 9 were not identified due to their absence on the last day of the program.

Caregivers were provided with a survey to measure the impact that the HEPs and propulsion infographics had for them and their children. This was a voluntary survey with 5 questions assessing days their children adhered to their allocated HEP, potential benefits seen from HEPs, potential change in propulsion pattern, and prospective adherence to HEPs in 3 formats. 3 questions were provided via free response, 1 question via a 5-point Likert scale from “Definitely Not” to “Definitely Yes”, and 1 question via 8-point Slider scale measuring days of the week from 0 to 7. This survey can be found in Appendix H.

Comparison between Pre- and Post-Assessment Results

Looking at the play-based HEP, of the 5 participants who were present for both the pre- and post-assessments, varied impacts in relation to ROM and strength differences were noted after 5 weeks of completing the HEP. Relative to shoulder ROM, 3 participants had an overall increase in ROM while 2 had no positive differences with ROM. 4 participants had a net positive difference with elbow ROM while 1 participant had a net negative difference with elbow ROM.

2 participants had a net positive difference with forearm ROM while 3 participants had a net negative difference with forearm ROM. 4 participants had a net positive difference with wrist ROM while 1 participant had a net negative difference with wrist ROM. 2 participants had a net positive difference with grip strength while 3 had a net negative difference with grip strength. Lastly, 3 participants had a net positive difference with pinch strength while 2 had a net negative difference with pinch strength.

Looking at the therapeutic exercise HEP, of the 9 participants who were present for both the pre- and post-assessments, as with the play-based HEP, varied impacts in relation to ROM and strength differences were noted after 5 weeks of completing their designated HEP. Relative to shoulder ROM, 1 participant had an overall increase in ROM while 8 had no positive differences with ROM. 5 participants had a net positive difference with elbow ROM while 4 participants had a net negative difference with elbow ROM. 3 participants had a net positive difference with forearm ROM while 6 participants had a net negative difference with forearm ROM. 2 participants had a net positive difference with wrist ROM while 7 participants had a net negative difference with wrist ROM. 5 participants had a net positive difference with grip strength while 4 had a net negative difference with grip strength. Lastly, 5 participants had a net positive difference with pinch strength while 4 had a net negative difference with pinch strength.

Discussing the caregiver survey results, results within this report were collected as of April 28th, 2024, due to time constraints for this project. However, additional results may still be collected. A total of 7 to 10 caregivers reported responses to the questions included in the survey. Of the 10 who responded for completion of exercises over a 7 day/week timeframe, the average number of days participants completed their HEPs was 3.77. The lowest number of days reported completing HEPs was 2 and the highest number of days reported averaged out to 5.50. Of the 8

who responded to a potential benefit from completing the exercises, 7 of 8 caregivers reported positive feedback with the outlier describing, “it is hard to tell with her regression she gets tired easily”. Of the 8 who responded to any noticed changes with manual wheelchair propulsion pattern, 7 of 8 caregivers reported positive feedback. Of the 7 who responded to if they will maintain future adherence to HEPs and best practices with propulsion, 3 responded “probably yes” and 4 responded “definitely yes”. No caregivers provided feedback for potential modifications they would provide for the HEPs or propulsion training.

Discussing the pediatric manual wheelchair users upper extremity pain assessment, of the 13 participants who completed the assessment during the first program session, 1 participant noted upper extremity pain. Pain was in the left shoulder and attributed to playing basketball. Upon completion of the program on the last day, 9 participants who completed the assessment in the first program session were evaluated. 1 participant who did not report pain during the first program session reported pain in bilateral shoulders during the fifth program session. Participant data was not obtained from the participant who reported pain during the first program session despite being present for the program.

Discussion

Reviewal of the evidence from the pre- and post-assessment results from the first program session to the last program session reveals the goals and objectives that the doctoral capstone student initially sought out were achieved in some light. Regarding the impact of the newly instilled play-based HEP and comparing the ROM and strength results to the established HEP, its viability to remain an alternative is warranted. Net differences in ROM and strength between the HEPs indicated that despite there being less participants who were present for both assessment days that received the play-based HEP, there were interesting trends noted. The play-

based HEP saw a significant difference with a seemingly positive impacted compared to the therapeutic exercise HEP with increases in shoulder and elbow ROM. After reviewing last year's doctoral capstone students results and noticing the impact the therapeutic exercise HEP had on shoulder, elbow, and wrist ROM compared to the control, it was important to incorporate less strenuous exercise on the shoulders, elbows, and wrists to see if ROM results would differ. The play-based HEP had less isolated shoulder exercises, less intense shoulder, elbow, and wrist exercises, and emphasized gross motor movements with many of the exercises which may have contributed to the differences in ROM between the two HEPs. The additions of a potentially strenuous HEP on the shoulder and elbow along with overuse that already occurs in these two joints among manual wheelchair users could help in explaining the varied results. Forearm ROM between both HEPs did not differ greatly, with no positive differences seen in the post assessment results. Grip strength and pinch strength for the therapeutic exercise HEP both showed positive differences overall among participants which given the results from last year's tests, was hoped to be replicated. Strength differences in participants who received hand strengthening putty exercises increased in both groups (Hoseinpour, 2023). In the play-based HEP, pinch strength showed a positive difference while grip strength overall did not increase among participants. This could be attributed to more focus on grip strengthening in the therapeutic exercise group along with a more targeted impact on intrinsic hand muscles with the different hand strengthening exercises provided. The pediatric manual wheelchair users upper extremity pain assessment provided a formidable indicator for measuring potential pain with occupation and for providing relevant upper extremity information that would be beneficial for the program to know of its participants. Lastly, reviewing the pain assessment results and seeing that the majority of the participants who completed the assessment did not feel any upper

extremity pain at the moment was encouraging as prevention would inevitably become the main focus.

Impact

This doctoral capstone project was created with the intention of preserving the upper extremities and preventing upper extremity pain, weakness, and injuries in Skills on Wheels participants due to manual wheelchair use. The HEP that was created was tailored specifically with children in mind, in order to provide volitional play-based activities for a randomized group of participants. Feedback obtained from the caregiver survey asking whether participants and caregivers saw a benefit of the HEP supports continued use for this HEP in future program sessions. Responses included, “Yes, she also had fun doing so”, “I see more confidence with her. She loves the games and skills”, “It was nice to have a plan for what we were doing at home”, and “He has increased his ability to complete tasks while wearing his back brace”. There was no negative feedback provided regarding future adherence. The propulsion infographic was created to provide participants with best practices for propelling themselves in their manual wheelchairs; it was later learned that upon getting fit for a wheelchair, many of the participants did not receive further education on how to propel themselves. Feedback obtained from the caregiver survey asking whether participants and caregivers saw a benefit from the propulsion education they received also supports continued use of this in future program sessions. Responses included, “He’s much more confident in it, and his motion seems smoother and more intentional”, “She was able to get her seat pan, and center of gravity fixed and may have helped her shoulders”, and “Yes, she can move her wheelchair a lot better”. Negative feedback included one response that indicated difficulty seeing change in propulsion. As mentioned in the results section, 4 caregivers responded, “Definitely Yes” and 3 caregivers responded “Probably Yes” on whether they intend

to continue to perform exercises and ensure best practice with propulsion after conclusion of Skills on Wheels.

For future sessions, continued use of the play-based HEP, propulsion infographic, and pain-based assessment would be beneficial. The play-based HEP may benefit from continued research into play-based interventions to add more volitional exercises while also understanding the sweet spot for performing these exercises on a daily basis. The play-based HEP was perceived well by participants, volunteers, and caregivers alike, again indicating that it would be worthwhile to maintain. Providing further education on propulsion would provide benefit to volunteers, caregivers, and participants. Skills on Wheels would benefit from further incorporating a formalized understanding of best practices with propulsion into the training for skills trainers and volunteers. Providing volunteers with greater knowledge on propulsion would then allow for them to be confident in educating participants on manual wheelchair propulsion, potentially leading to better outcomes. Subjective observation from program sessions displayed that there was difficulty to enforce volunteers to do this, further education and reminders could allow for more consistent education being provided to participants by volunteers. Skills on Wheels may also benefit from incorporating Inertial Measurement Units to provide information on propulsion through joint angle rotations during propulsion. This could bring added benefit through bringing greater understanding of the muscles responsible for manual wheelchair propulsion in the pediatric population and to gain understanding on how the majority of participants propel themselves. There largely remains a lack of literature exploring this. Lastly, the pain-based assessment would also benefit from continued use, although enforcement of completion and providing more understanding to skills trainers thorough education on its usage and impact is important. Many participants did not complete the assessment during either session

and this is attributed to volunteers not completing it with their participants. A presumed lack of understanding contributed to difficulties completing the assessment during assessment days and inaccurate completion.

Overall, this project and its goals and objectives aimed to provide a benefit for the pediatric manual wheelchair users population. Continued research with Skills on Wheels and outside of Skills on Wheels is important to gain an understanding of how pain, weakness, and injury can be prevented among children who use wheelchairs to ensure they have optimal long-term outcomes.

Limitations

This study ran into several limitations during the course of completing this doctoral capstone project. Several of the limitations were tied to the nature of the program itself while the rest were different areas noticed that could be improved upon in the future. Skills on Wheels as mentioned is a 5-week long program; given this, there was a limited timeframe for a concrete follow-up and results to be gained. Despite attempting to promote buy-in and providing education to caregivers, it was hard to ensure consistent adherence to HEPs and best practices in terms of propulsion from participants as there was no way to monitor this best while they were home. Regarding program sessions themselves, measurement bias during the collection of the upper extremity and pain assessment data most likely also occurred. This could be attributed to a lack of oversight when completing the assessments above, resulting in inaccurate testing and distribution. In addition, with the pain assessment, some participants did not get this completed with their skills trainers despite skills trainers being provided with the pain assessment. Next, despite receiving education on best practices for propulsion, a guide for propulsion, and being encouraged to critique participants' propulsion methods during program sessions; enforcement of

this was not overseen and adaptations in propulsion may not have occurred as hoped. Alternative methods not incorporated for assisting to change propulsion also may have benefited from being used as these could have had a broader impact compared to verbal feedback. Lastly, concerning participants, inconsistencies occurred due to losing participants to follow-up on the last assessment day and with participants being assessed who were not formally present for the first assessment day.

Conclusion

Skills on Wheels is a program that was developed to address the fears and anxieties that pediatric manual wheelchair users face when using their manual wheelchairs in the community and at home. The creation of this wheelchair confidence skills program has helped to address these concerns, measuring where a participant is when completing various wheelchair skills both at the beginning of the program and once it is finished. Since its creation as a program - data, and research has been collected from not only the program itself but through other similar studies showing the impacts that educating manual wheelchair propulsion and implementing upper extremity exercise can have on manual wheelchair users. This doctoral capstone project aimed to investigate upper extremity kinematics and propulsion ergonomics among manual wheelchair users to provide best practices for participants. To understand how Skills on Wheels' current upper extremity HEP could be adapted or replaced to benefit its pediatric population to help prevent upper extremity pain and to develop a pediatric-friendly upper extremity pain assessment implemented for Skills on Wheels to provide pertinent upper extremity data to further enhance outcomes among participants. These were all created in mind to reduce repetitive strain injuries and resulting weakness that ensues, as well as minimize potential prolonged adverse health

effects due to manual wheelchair strain injuries, poor biomechanics and ergonomics from manual wheelchair propulsion, and potential concerns related to upper extremity pain.

References

Abrams, A. (2020, July 23). *30 years post Ada, the fight for Disability Access Continues*. Time. Retrieved March 26, 2023, from https://time.com/5870468/americans-with-disabilities-act-coronavirus/

Chase, T., Mendoza, K., Rager, C., Stiens, M., Loeser, M., Stead, T., Kozlowski, W., Van Antwerp, L., Camilleri, J., & O'Neil, J. (2024). Skills on wheels: Initial pre-post findings from a pilot study of a pediatric wheelchair skills training program. *Disability and Rehabilitation: Assistive Technology*, 1–8. https://doi.org/10.1080/17483107.2024.2324146

Dysterheft, J. L., Rice, I. M., & Rice, L. A. (2015). Influence of handrim wheelchair propulsion training in adolescent wheelchair users, a pilot study. *Frontiers in bioengineering and biotechnology*, *3*, 68. https://doi.org/10.3389/fbioe.2015.00068

Edmonds, E. W., Bastrom, T. P., Roocroft, J. H., Calandra-Young, V. A., & Pennock, A. T. (2017). The Pediatric/Adolescent Shoulder Survey (PASS): A Reliable Youth Questionnaire With Discriminant Validity and Responsiveness to Change. *Orthopaedic journal of sports medicine*, *5*(3), 2325967117698466. https://doi.org/10.1177/2325967117698466

Harvey, L. A., & Glinsky, J. V. (2018, September 3). *Clinimetrics: The wheelchair user's shoulder pain index (WUSPI)*. Journal of Physiotherapy. https://www.sciencedirect.com/science/article/pii/S1836955318300791?via%3Dihub

Hoseinpour, N. (2023, May 1). *Skills on wheels: Development and benefits of an upper extremity home exercise program*. IUPUI ScholarWorks. https://scholarworks.iupui.edu/items/5d5f4e28-1e2c-4e60-a0e3-0a723212cee9

Iwasaki, Y., Springett, J., Dashora, P., McLaughlin, A.-M., & McHugh, T.-L. (2014). Youthguided youth engagement: Participatory action research (PAR) with high-risk, marginalized youth. Child & Youth Services, 35(4), 316–342. https://doi.org/10.1080/0145935X.2014.962132

Kwarciak, A. M., Turner, J. T., Guo, L., & Richter, W. M. (2012). The effects of four different stroke patterns on manual wheelchair propulsion and upper limb muscle strain. *Disability and Rehabilitation: Assistive Technology*, *7*(6), 459–463. https://doi.org/10.3109/17483107.2011.650781

Leonardis, J. M., Schnorenberg, A. J., Vogel, L. C., Harris, G. F., & Slavens, B. A. (2022). The Influence of Age at Pediatric-Onset Spinal Cord Injury and Years of Wheelchair Use on Shoulder Complex Joint Dynamics During Manual Wheelchair Propulsion. *Archives of rehabilitation research and clinical translation*, *4*(4), 100235. https://doi.org/10.1016/j.arrct.2022.100235

Lv, S., Chen, Y., Liu, M., Qin, L., Liu, Z., Liu, W., Cui, M., Zhang, X., Yan, H., Ning, F., Zhang, H., & Xu, Y. (2022). Progress of Proprioceptive Training in the Treatment of Traumatic Shoulder Instability. *Computational and mathematical methods in medicine*, *2022*, 1429375. https://doi.org/10.1155/2022/1429375 (Retraction published Comput Math Methods Med. 2023 Sep 27;2023:9812435)

Mason, B., Warner, M., Briley, S., Goosey-Tolfrey, V., & Vegter, R. (2020). Managing shoulder pain in manual wheelchair users: a scoping review of conservative treatment interventions. *Clinical rehabilitation*, *34*(6), 741–753. https://doi.org/10.1177/0269215520917437

McMillan, I. R. (2016, September 9). *The biomechanical frame of reference in occupational therapy*. Musculoskeletal Key. Retrieved March 26, 2023, from https://musculoskeletalkey.com/the-biomechanical-frame-of-reference-in-occupational-therapy/

Mulroy, S. J., Hatchett, P., Eberly, V. J., Haubert, L. L., Conners, S., & Requejo, P. S. (2015). Shoulder Strength and Physical Activity Predictors of Shoulder Pain in People With Paraplegia From Spinal Injury: Prospective Cohort Study. *Physical therapy*, *95*(7), 1027–1038. https://doi.org/10.2522/ptj.20130606

O'Connell, Dennis G., and Robert Barnhart. "Improvement in Wheelchair Propulsion in Pediatric Wheelchair Users through Resistance Training: A Pilot Study." *Archives of Physical Medicine and Rehabilitation*, vol. 76, no. 4, Apr. 1995, pp. 368–372, https://doi.org/10.1016/s0003-9993(95)80663-6. Accessed 2 Apr. 2020.

Rammer, Jacob R. PhD; Krzak, Joseph J. PT, PCS, PhD; Slavens, Brooke A. PhD; Winters, Jack M. PhD; Riedel, Susan A. SM, PE; Harris, Gerald F. PhD, PE. Considering Propulsion Pattern in Therapeutic Outcomes for Children Who Use Manual Wheelchairs. Pediatric Physical Therapy 31(4):p 360-368, October 2019. | DOI: 10.1097/PEP.0000000000000649

Silvestri, J. L., Lawson, S., & Sadowsky, C. (2022). Chronic Shoulder Pain in Manual Wheelchair (MWC) Users with Spinal Cord Injury (SCI): The Lived Experience. The Open Journal of Occupational Therapy, 10(1), 1-12. https://doi.org/10.15453/2168-6408.1867

Slavens, B. A., Schnorenberg, A. J., Aurit, C. M., Tarima, S., Vogel, L. C., & Harris, G. F. (2015). Biomechanics of Pediatric Manual Wheelchair Mobility. *Frontiers in Bioengineering and Biotechnology*, *3*. https://doi.org/10.3389/fbioe.2015.00137

Slowik, J. S., Requejo, P. S., Mulroy, S. J., & Neptune, R. R. (2016). The influence of wheelchair propulsion hand pattern on upper extremity muscle power and stress. *Journal of biomechanics*, *49*(9), 1554–1561. https://doi.org/10.1016/j.jbiomech.2016.03.031

Weinstock-Zlotnick, G., & Mehta, S. P. (2019). A systematic review of the benefits of occupation-based intervention for patients with upper extremity musculoskeletal disorders. *Journal of hand therapy : official journal of the American Society of Hand Therapists*, *32*(2), 141–152. https://doi.org/10.1016/j.jht.2018.04.001

Appendix A

Interview with the Site

Table A

Interview Questions	**Interview Responses**
What Upper Extremity (UE) data has been measured in years past?	"Grip, pinch, ROM, MMT."
What is the goal of measuring the participants' Upper Extremity Range of Motion (ROM)/Manual Muscle Testing (MMT)? • Expanding upon this, what is the ultimate need/ goal for next spring's Skills on Wheels session given the data we are getting this spring and what we are aiming to get next spring?	"Research shows manual wheelchair users have UE strain injuries, focusing on that early on can help decrease surgeries and long-term injuries in the future." • "Identifying areas in which we can improve patient capabilities and outcomes, identify prevention strategies to avoid injuries, and identify a long-term prevention program for wheelchair users."
In years past, has ROM and MMT data changed in the participants as the month progressed?	"There was a change last year, which decreased over the course of time. ROM decreased last year."
What kind of contractures/ injuries do these children suffer from (due to prolonged wheelchair usage)?	"Not necessarily contractures, but mostly weakness from wheelchair use which can lead to differences in wheelchair movement."
What is the desired goal with measuring ROM/ MMT data using Inertial Measurement Units and pinch/ dynamometers?	"The biggest component is identifying how often during the cycle they are moving within that same pattern. For example, they're moving this many times within a hundred feet, so many yards. Increase that by how many yards they move. They could do more with the data that we find. We need to get them to work right."
Are there any interventions done to help these children with improving their strength?	"Home Exercise Programs (HEP), stretching programs, this could be something that could

	be done. Morgan or another student could do this for their capstone in the future."
What can be done in future Skills on Wheels sessions with the data that we gather?	"We can identify what sort of areas are, do we need to do warm-ups and cool-downs. Is there an exercise program that can happen during Skills on Wheels, what's our motto to prevent injuries in the future?"
How could I expand on the last capstone student's work? • What work did they do and how could I expand upon that for next Spring?	"Continuing the HEP process and what worked this year and what do we need to do for next year, continuing what worked. Especially since we have carryover clients, seeing how they increase strength and endurance. Seeing the change from year to year."

Appendix B

Skills on Wheels: Exercise While Playing! A Handy Handout

QR Code with Helpful Video	
Scan the QR code on the right for a video to help you learn how to do all of the exercises correctly!	

Shoulder Stretches and Exercises	

Shoulder Proprioceptive Stretch	• Ball Roll
	  ○ *By yourself,* roll a ball on the wall or a table using the palms of your hands up and down, side to side, and in circles. Keep your arms straight.
	  ○ Write out the ABCs while rolling a ball!
	• Weight Shift
	  ○ By yourself, put both arms on a table and lean onto them moving your body's weight from side to side.

Flexion	• Ball Toss
	  o By *yourself,* using one or both of your arms, facing the wall throw a ball off a hard surface like a wall and catch it.
	  o With a partner, toss a ball to them using one or both arms over your head.
	• Balloon Tap
	  o *By yourself or with a partner,* tap a balloon above your head making sure it stays above your shoulders.
	• Reaching
	  o *By yourself,* reach forward for things placed on a wall/shelf or the ground, straightening your arms to grab that object.

Abduction/Adduction	• Pretend Coloring
	  o By *yourself,* using a paintbrush, marker, etc. pretend you're coloring your wall at home.
	• Balloon Finger Walk
	  o *By yourself,* facing sideways against a wall move a balloon up and down on a wall with each hand.
	
	Optional for those with a dry-erase board/chalk wall:
	
	• Painting/Coloring
	  o *By yourself,* paint or color with your arms facing away from the side of your body, using either your right or your left hand!

External Rotation	• Mitt Catching Ball Game
	  o *With a partner,* catch a sticky ball with your baseball mitt. Make a "U" shape with your left or right arm when catching the ball.
	  o *By yourself,* throw a ball above your head and catch the ball with the mitt over your head.
	• Zoom Ball
	  o *With a partner,* grip tightly onto the zoom ball handles and make a "U" with your arms away from the sides of your body to send the ball away.

Internal Rotation	• Finger Guessing Game
	  o *With a partner,* bring your arm or both arms behind your back while they guess how many fingers you hold up. Form a "U" behind your back.
	• Zoom Ball
	  o *With a partner,* using one or both arms, touch your upper body with your arm when moving the ball back and forth with your partner.
	• Mitt Catching Ball Game
	  o *With a partner,* catch a sticky ball with your baseball mitt. Hold the mitt by your belly button when catching the ball.

Elbow, Forearm, & Wrist Range of Motion Exercises	

Elbow Flexion/Extension	• Balloon/Ball Tap With a Broom
	  ○ *With a partner,* use a bar held in both hands to hit a balloon/ball up above your head as your partner tosses something to you.
	  ○ *By yourself,* hit the balloon up in the air bringing this bar up and down, while keeping the balloon right above your head.
	• Volleyball
	  ○ *With a partner or by yourself,* hit a volleyball with a partner.

Pronation/Supination	• Bean Bag Flip with Spatula ○ *By yourself,* flip a bean bag using a spatula across your body from one surface into a box or another surface, flip it down into the box, and turn your forearm.

Radial/Ulnar Deviation	• Kleenex Box "Air" Hockey
	  o *With a partner,* play "air" hockey using a Kleenex box/a similar item and a small ball/similar item at arm level on a table. Move your wrist toward your thumb and pinky when using the box to hit the hockey puck item back to your partner.
	• Frisbee
	  o *With a partner,* toss a frisbee back and forth, move your wrist toward your thumb and pinky when throwing!
	• Legos
	  o *By yourself or with a partner,* move your wrist toward your thumb and pinky when grabbing legos and building them!

Wrist Flexion/Extension	• Ball toss between hands
	  o *By yourself,* toss a ball from hand to hand. Move your wrist as far as you can up and down when throwing/catching.
	• Painting/Drawing
	  o *By yourself,* while painting or drawing move your wrists up and down as far as you can.

Hand Strengthening Exercises	
Palmar Pinch, Extension, IP Fisting	• Play Dough/Theraputty Pinch o By yourself or with a partner, add objects such as beads, legos, or figurines to find in playdough/theraputty. o Larger objects to find make this easier! o Stretch your fingers into the putty, pressing them in as much as possible.
MP Flexion, Palmar Pinch, Extension, Lateral Pinch	• Rubber Bands o *With a partner,* make a pegboard that you use to make different designs or shapes using rubber bands. o Use Rubber bands to stretch your fingers out wide trying to hold them outstretched as long as you can!
Grip Strength, IP Fisting, Finger Extension	• Theraputty Figures o *By yourself,* make different shapes or figures with the color putty that is hard for you to play with. o *By yourself,* squeeze the putty into a ball, then stretch the putty out and use your fingers!
MP Flexion, Palmar Pinch, Adduction, Flexion	• Arts and Crafts o *By yourself or with a partner,* cut many different shapes with scissors. Or o *By yourself,* crumple a piece of paper, form a ball, and make an art design. • Legos o *By yourself,* make sure to grab onto legos trying to use only your finger muscles to build structures.

Core Strengthening Exercises

Abdominal Strengthening	• Cup Stacking
	  ○ *By yourself,* with different cups, reach across the body and toward different cups in front of you, building a tower.
	  ○ You can reach for things on the floor or a table
	• Balloon tap
	  ○ *With a partner,* hit a balloon/ball to your partner, and rotate your trunk as you tap the balloon!
	  ○ *By yourself,* hit the balloon up in the air rotating your trunk in your wheelchair.

Tips for Play-Based Exercises

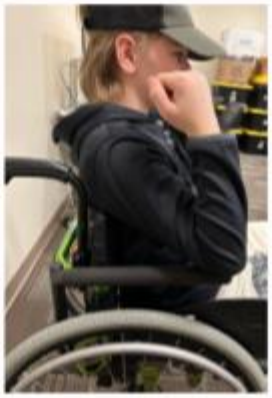
- Exercises to be done once or twice a day at most.
- Many of these exercises will include several of the different arm movements in one play activity since we're using big, gross motor movements.
- Zoom ball helps include a lot of the big shoulder and elbow exercises.
- Make sure to follow the order of the exercises from the top to the bottom.
- For exercises you can do by yourself, do them for around 5–10 minutes each, although if you can and want to make it harder, longer is better!
- For exercises with a partner, do them for around 5 minutes, although if you can and want to make it harder, longer is better!
- For the theraputty, the yellow is the easiest color to stretch with the red being slightly harder, then the green being slightly harder, and the blue being the firmest putty.
- Do not overdo exercises, once you feel like your muscles are getting tired you should be about done with that exercise and can move on to the next one!
- The light red box on the left under each exercise provides the different movements we want to achieve by doing the different play-based exercises.
- For any questions about your home exercise program, please email at: abelyaye@iu.edu or mealbrig@iu.edu

Appendix C

Skills on Wheels: Handy Handout

Shoulder Exercises	
Flexion	• Bring your arms straight up • Reach for the ceiling 
Extension	• Bring your arms straight back 
Abduction	• Jumping jack arms 

External Rotation	• Start with your arms bent at 90 degrees • Bring your forearm out away from you while arm is still bent 
Internal Rotation	• Start with your arms bent at 90 degrees • While your arm is still bent, bring forearm in towards your belly  

Elbow, Forearm, & Wrist Range of Motion Exercises	
Elbow Extension	• Straighten your arm all the way out 
Elbow Flexion	• Bend your elbows in • Show off your muscles! 
Pronation	• Palms face down 

Supination	• Palms face up towards the ceiling • Like you are holding a bowl of soup 
Radial Deviation	• Start with arms flat on the table • Move your wrist towards your belly 
Ulnar Deviation	• Start with your hands flat on the table • Move your wrist away from your belly 

Supination	• Palms face up towards the ceiling • Like you are holding a bowl of soup 
Radial Deviation	• Start with arms flat on the table • Move your wrist towards your belly 
Ulnar Deviation	• Start with your hands flat on the table • Move your wrist away from your belly 

Shoulder Strengthening Exercises	
Abduction	• Start with threading your Theraband under one leg • Now thread the Theraband under the other leg • Weight-shift your body so that you are sitting on the Theraband • Bring your arms straight up and elbows are out 
Flexion	• Bring the Theraband straight up • Reaching for the ceiling! • Tip: Wrap Theraband around the push-handle 

Extension	• Punch down with the Theraband • Tip: Wrap Theraband around the push-handle 
External Rotation	• Wrap Theraband around the arm rest • Start with elbow at 90 degrees and bring arm away from your belly 
Internal Rotation	• Wrap Theraband around the arm rest • Start with elbow at 90 degrees and bring arm towards your belly 

Hand Strengthening Exercises	
Grip Strength	• Squeeze the putty with all your fingers • General squeezing to help with making a stronger fist 
IP Fisting	• Make "Cat Claw" into putty • Bend the tips of your fingers into the putty and keep knuckles straight 
Finger Extension	• Roll out the putty to make a snake • Work on straightening your fingers when rolling 

MP Flexion	• "Sandwich" hold position • Bend your knuckles and keep fingers straight 
Lateral Pinch	• Press into putty like you are holding a key • Putty should be in between thumb and index finger 
Extension	• First make putty into "donut hole" • Squeeze your fingers into the "donut hole" • Spread out your fingers into "donut hole" • **Note**: the smaller the donut hole, the more resistive 

Palmar Pinch	• With each finger, pinch into the putty • Tip to tip pinches 
Adduction	• Roll up putty into snake and place putty into between 2 fingers • "Scissor" the putty 
Flexion	• Squeeze into putty by bending knuckles and keeping finger tips straight 

Tips for Exercises

- Exercises to be completed once a day
- For each exercise assigned, complete 10-15 times each
- If exercises become difficult, take a break from them
- Do not over do exercises!
- For Theraband exercises, the closer you hold the Theraband, the more resistance there is. The further out you hold the Theraband, the less resistance there is. This increases the difficulty of exercises.
- For putty exercises, make sure you are completing these exercises on a hard and flat surface because putty can stick to fabrics. Always store the putty in containers provided.
- Posture ⟶ Make sure you are sitting up straight up in your wheelchair and feet flat on foot rests.
- For any questions about your home exercise program, please email at: **mealbrig@iu.edu**.

Appendix D

Participant #
Name:

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)		
Shoulder Extension (0-60)		
Shoulder Abduction (0-180)		
Shoulder External Rotation (0-90)		
Shoulder Internal Rotation (0-60)		
Elbow Extension (0)		
Elbow Flexion (0-150)		
Forearm Pronation (0-90)		
Forearm Supination (0-90)		
Wrist Flexion (0-80)		
Wrist Extension (0-70)		
Radial Deviation (0-20)		
Ulnar Deviation (0-30)		

(Grip)

	Left Hand	Right Hand
Grip Trial # 1		
Grip Trial # 2		
Grip Trial #3		
Average Grip		

(Lateral – Key Hold)

	Left Hand	Right Hand
Pinch #1		
Pinch #2		
Pinch #3		
Average Pinch		

Appendix E

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 1

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	176	180
Shoulder Extension (0-60)	90	90
Shoulder Abduction (0-180)	175	170
Shoulder External Rotation (0-90)	93	94
Shoulder Internal Rotation (0-60)	75	72
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	140	140
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	85	80
Wrist Flexion (0-80)	55	60
Wrist Extension (0-70)	80	80
Radial Deviation (0-20)	33	30
Ulnar Deviation (0-30)	30	30

(Grip)

	Left Hand	Right Hand
Average Grip	25.6333	24.1667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	8.03333	9.4

Group 2 Post-Measurements (Therapeutic-Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	180	180
Shoulder Extension (0-60)	50	50
Shoulder Abduction (0-180)	180	180

Shoulder External Rotation (0-90)	90	90
Shoulder Internal Rotation (0-60)	60	60
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	122	124
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	90	90
Wrist Flexion (0-80)	55	60
Wrist Extension (0-70)	60	50
Radial Deviation (0-20)	15	10
Ulnar Deviation (0-30)	30	30

(Grip)

	Left Hand	Right Hand
Average Grip	27.9	29.07

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	9.5	9.63

Group 2 Pre-Measurements (Therapeutic-Exercise Exercises)

Participant # 2

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	165	180
Shoulder Extension (0-60)	40	90
Shoulder Abduction (0-180)	145	170
Shoulder External Rotation (0-90)	60	94
Shoulder Internal Rotation (0-60)	51	72
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	120	140
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	90	80
Wrist Flexion (0-80)	70	60
Wrist Extension (0-70)	50	80

Radial Deviation (0-20)	15	30
Ulnar Deviation (0-30)	20	30

(Grip)

	Left Hand	Right Hand
Average Grip	25.6333	24.1667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	8.03333	9.4

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	170	165
Shoulder Extension (0-60)	85	80
Shoulder Abduction (0-180)	160	160
Shoulder External Rotation (0-90)	45	38
Shoulder Internal Rotation (0-60)	55	60
Elbow Extension (0)	5	0
Elbow Flexion (0-150)	140	140
Forearm Pronation (0-90)	75	60
Forearm Supination (0-90)	90	90
Wrist Flexion (0-80)	85	80
Wrist Extension (0-70)	50	55
Radial Deviation (0-20)	20	30
Ulnar Deviation (0-30)	30	20

(Grip)

	Left Hand	Right Hand
Average Grip	11.5	12.4

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	30.6	33.8

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 3

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	165	120
Shoulder Extension (0-60)	66	68
Shoulder Abduction (0-180)	148	156
Shoulder External Rotation (0-90)	80	87
Shoulder Internal Rotation (0-60)	57	40
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	140	140
Forearm Pronation (0-90)	85	90
Forearm Supination (0-90)	80	80
Wrist Flexion (0-80)	65	65
Wrist Extension (0-70)	55	50
Radial Deviation (0-20)	20	20
Ulnar Deviation (0-30)	20	20

(Grip)

	Left Hand	Right Hand
Average Grip	6.53333	6.93333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	3.3	3.56667

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	125	140
Shoulder Extension (0-60)	0	0
Shoulder Abduction (0-180)	160	145
Shoulder External Rotation (0-90)	50	80
Shoulder Internal Rotation (0-60)	45	70

Elbow Extension (0)	0	0
Elbow Flexion (0-150)	150	150
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	90	90
Wrist Flexion (0-80)	45	65
Wrist Extension (0-70)	45	45
Radial Deviation (0-20)	30	15
Ulnar Deviation (0-30)	15	15

(Grip)

	Left Hand	Right Hand
Average Grip	8.8	10.78

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	5.9	4.8

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 4

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	168	180
Shoulder Extension (0-60)	32	45
Shoulder Abduction (0-180)	172	168
Shoulder External Rotation (0-90)	70	99
Shoulder Internal Rotation (0-60)	30	36
Elbow Extension (0)	10	5
Elbow Flexion (0-150)	132	135
Forearm Pronation (0-90)	75	76
Forearm Supination (0-90)	70	75
Wrist Flexion (0-80)	70	65
Wrist Extension (0-70)	45	55
Radial Deviation (0-20)	15	25
Ulnar Deviation (0-30)	25	32

(Grip)

	Left Hand	Right Hand
Average Grip	9.03333	11.0667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	5.1	5.73333

Group 1 Post-Measurements (Play-Based Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	165	165
Shoulder Extension (0-60)	50	80
Shoulder Abduction (0-180)	165	150
Shoulder External Rotation (0-90)	60	60
Shoulder Internal Rotation (0-60)	60	60
Elbow Extension (0)	5	0
Elbow Flexion (0-150)	145	145
Forearm Pronation (0-90)	45	75
Forearm Supination (0-90)	55	75
Wrist Flexion (0-80)	85	60
Wrist Extension (0-70)	45	45
Radial Deviation (0-20)	20	15
Ulnar Deviation (0-30)	25	30

(Grip)

	Left Hand	Right Hand
Average Grip	10	9.2

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	5.03	5.77

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 5

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	145	160
Shoulder Extension (0-60)	63	30
Shoulder Abduction (0-180)	130	135
Shoulder External Rotation (0-90)	90	90
Shoulder Internal Rotation (0-60)	35	50
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	145	145
Forearm Pronation (0-90)	70	70
Forearm Supination (0-90)	75	65
Wrist Flexion (0-80)	65	75
Wrist Extension (0-70)	70	60
Radial Deviation (0-20)	20	20
Ulnar Deviation (0-30)	25	25

(Grip)

	Left Hand	Right Hand
Average Grip	14.6667	17.0333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	7.53333	7.13333

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	160	150
Shoulder Extension (0-60)	68	50
Shoulder Abduction (0-180)	143	152
Shoulder External Rotation (0-90)	77	75
Shoulder Internal Rotation (0-60)	50	85
Elbow Extension (0)	9	0
Elbow Flexion (0-150)	135	135
Forearm Pronation (0-90)	65	70

Forearm Supination (0-90)	65	75
Wrist Flexion (0-80)	43	52
Wrist Extension (0-70)	45	35
Radial Deviation (0-20)	21	29
Ulnar Deviation (0-30)	21	29

(Grip)

	Left Hand	Right Hand
Average Grip	19.1	42.3

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	7.17	6.53

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 6

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	130	155
Shoulder Extension (0-60)	55	45
Shoulder Abduction (0-180)	130	135
Shoulder External Rotation (0-90)	58	85
Shoulder Internal Rotation (0-60)	45	37
Elbow Extension (0)	10	12
Elbow Flexion (0-150)	136	144
Forearm Pronation (0-90)	65	80
Forearm Supination (0-90)	80	75
Wrist Flexion (0-80)	50	30
Wrist Extension (0-70)	30	55
Radial Deviation (0-20)	15	5
Ulnar Deviation (0-30)	20	20

(Grip)

	Left Hand	Right Hand
Average Grip	14.9333	11.1

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	6.5	4.93333

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	100	120
Shoulder Extension (0-60)	70	40
Shoulder Abduction (0-180)	130	125
Shoulder External Rotation (0-90)	20	35
Shoulder Internal Rotation (0-60)	50	45
Elbow Extension (0)	5	5
Elbow Flexion (0-150)	140	140
Forearm Pronation (0-90)	70	80
Forearm Supination (0-90)	40	40
Wrist Flexion (0-80)	60	50
Wrist Extension (0-70)	35	45
Radial Deviation (0-20)	0	0
Ulnar Deviation (0-30)	30	20

(Grip)

	Left Hand	Right Hand
Average Grip	15.1	11.4

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	5.87	3.9

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 7

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	140	100
Shoulder Extension (0-60)	55	70

Shoulder Abduction (0-180)	120	105
Shoulder External Rotation (0-90)	40	80
Shoulder Internal Rotation (0-60)	60	78
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	110	140
Forearm Pronation (0-90)	75	90
Forearm Supination (0-90)	75	90
Wrist Flexion (0-80)	60	45
Wrist Extension (0-70)	75	65
Radial Deviation (0-20)	20	20
Ulnar Deviation (0-30)	15	15

(Grip)

	Left Hand	Right Hand
Average Grip	5.9	12.8333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	3.9	3.25

Group 1 Post-Measurements (Play-Based Exercises)

*ROM/Strength testing not undergone due to the participant's absence during the second assessment date

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 8

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	150	150
Shoulder Extension (0-60)	65	75
Shoulder Abduction (0-180)	140	150
Shoulder External Rotation (0-90)	55	40
Shoulder Internal Rotation (0-60)	65	30
Elbow Extension (0)	0	0

Elbow Flexion (0-150)	150	135
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	90	90
Wrist Flexion (0-80)	32	60
Wrist Extension (0-70)	60	60
Radial Deviation (0-20)	30	35
Ulnar Deviation (0-30)	5	20

(Grip)

	Left Hand	Right Hand
Average Grip	90.1333	84.1667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	18.2333	18.1667

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	145	135
Shoulder Extension (0-60)	75	65
Shoulder Abduction (0-180)	145	140
Shoulder External Rotation (0-90)	45	45
Shoulder Internal Rotation (0-60)	65	60
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	140	135
Forearm Pronation (0-90)	75	80
Forearm Supination (0-90)	90	80
Wrist Flexion (0-80)	45	60
Wrist Extension (0-70)	80	80
Radial Deviation (0-20)	40	40
Ulnar Deviation (0-30)	35	30

(Grip)

	Left Hand	Right Hand
Average Grip	76.93	85.93

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	19.4	16.17

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 9

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	115	135
Shoulder Extension (0-60)	35	55
Shoulder Abduction (0-180)	76	144
Shoulder External Rotation (0-90)	70	85
Shoulder Internal Rotation (0-60)	40	40
Elbow Extension (0)	50	175
Elbow Flexion (0-150)	144	154
Forearm Pronation (0-90)	85	90
Forearm Supination (0-90)	90	70
Wrist Flexion (0-80)	15-20	60
Wrist Extension (0-70)	15-20	45
Radial Deviation (0-20)	10	10
Ulnar Deviation (0-30)	10-15	10-15

(Grip)

	Left Hand	Right Hand
Average Grip	10.5333	9.36667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	5.06667	3.56667

Group 1 Post-Measurements (Play-Based Exercises)

*ROM/Strength testing not undergone due to the participant's absence during the second assessment date

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 10

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	170	170
Shoulder Extension (0-60)	70	65
Shoulder Abduction (0-180)	169	168
Shoulder External Rotation (0-90)	85	85
Shoulder Internal Rotation (0-60)	38	55
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	135	133
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	85	80
Wrist Flexion (0-80)	60	80
Wrist Extension (0-70)	73	70
Radial Deviation (0-20)	25	28
Ulnar Deviation (0-30)	27	25

(Grip)

	Left Hand	Right Hand
Average Grip	24.8333	24.4333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	6.7	8

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	156	154
Shoulder Extension (0-60)	59	56
Shoulder Abduction (0-180)	143	160
Shoulder External Rotation (0-90)	63	72
Shoulder Internal Rotation (0-60)	58	60
Elbow Extension (0)	10	9

Elbow Flexion (0-150)	143	148
Forearm Pronation (0-90)	80	80
Forearm Supination (0-90)	90	60
Wrist Flexion (0-80)	60	50
Wrist Extension (0-70)	65	65
Radial Deviation (0-20)	10	10
Ulnar Deviation (0-30)	45	40

(Grip)

	Left Hand	Right Hand
Average Grip	22.63	22.9

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	7.57	7.7

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 14

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	152	160
Shoulder Extension (0-60)	65	65
Shoulder Abduction (0-180)	152	151
Shoulder External Rotation (0-90)	50	42
Shoulder Internal Rotation (0-60)	30	80
Elbow Extension (0)	9	11
Elbow Flexion (0-150)	130	114
Forearm Pronation (0-90)	60	60
Forearm Supination (0-90)	50	60
Wrist Flexion (0-80)	45	75
Wrist Extension (0-70)	50	59
Radial Deviation (0-20)	15	35
Ulnar Deviation (0-30)	35	20

(Grip)

	Left Hand	Right Hand

Average Grip	14.5	13.0333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	3.03333	4.63333

Group 1 Post-Measurements (Play-Based Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	171	154
Shoulder Extension (0-60)	49	54
Shoulder Abduction (0-180)	150	130
Shoulder External Rotation (0-90)	45	40
Shoulder Internal Rotation (0-60)	76	80
Elbow Extension (0)	8	0
Elbow Flexion (0-150)	115	133
Forearm Pronation (0-90)	90	60
Forearm Supination (0-90)	70	75
Wrist Flexion (0-80)	70	62
Wrist Extension (0-70)	68	55
Radial Deviation (0-20)	15	28
Ulnar Deviation (0-30)	30	30

(Grip)

	Left Hand	Right Hand
Average Grip	12.37	12.57

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	3.2	4.73

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 15

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	140	150
Shoulder Extension (0-60)	50	55
Shoulder Abduction (0-180)	140	70
Shoulder External Rotation (0-90)	50	65
Shoulder Internal Rotation (0-60)	47	40
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	110	100
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	90	90
Wrist Flexion (0-80)	60	45
Wrist Extension (0-70)	55	60
Radial Deviation (0-20)	20	20
Ulnar Deviation (0-30)	30	25

(Grip)

	Left Hand	Right Hand
Average Grip	21.9	30.4667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	8.46667	8.73333

Group 1 Post-Measurements (Play-Based Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	160	160
Shoulder Extension (0-60)	65	70
Shoulder Abduction (0-180)	170	170
Shoulder External Rotation (0-90)	25	35
Shoulder Internal Rotation (0-60)	45	50
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	145	145
Forearm Pronation (0-90)	75	70

Forearm Supination (0-90)	80	85
Wrist Flexion (0-80)	75	80
Wrist Extension (0-70)	65	65
Radial Deviation (0-20)	30	30
Ulnar Deviation (0-30)	30	20

(Grip)

	Left Hand	Right Hand
Average Grip	30.8	31.1

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	11.53	11.47

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 16

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	165	160
Shoulder Extension (0-60)	75	65
Shoulder Abduction (0-180)	184	172
Shoulder External Rotation (0-90)	90	90
Shoulder Internal Rotation (0-60)	80	80
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	130	128
Forearm Pronation (0-90)	85	85
Forearm Supination (0-90)	80	80
Wrist Flexion (0-80)	65	65
Wrist Extension (0-70)	70	66
Radial Deviation (0-20)	30	30
Ulnar Deviation (0-30)	20	20

(Grip)

	Left Hand	Right Hand
Average Grip	26.7667	26.4667

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	12.8667	9.06667

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	153	140
Shoulder Extension (0-60)	68	72
Shoulder Abduction (0-180)	158	156
Shoulder External Rotation (0-90)	76	75
Shoulder Internal Rotation (0-60)	74	62
Elbow Extension (0)	1	8
Elbow Flexion (0-150)	157	138
Forearm Pronation (0-90)	70	65
Forearm Supination (0-90)	45	75
Wrist Flexion (0-80)	40	60
Wrist Extension (0-70)	55	60
Radial Deviation (0-20)	20	28
Ulnar Deviation (0-30)	45	40

(Grip)

	Left Hand	Right Hand
Average Grip	30.1	27

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	9.067	9.27

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 18

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	170	170
Shoulder Extension (0-60)	63	60

Shoulder Abduction (0-180)	162	173
Shoulder External Rotation (0-90)	90	88
Shoulder Internal Rotation (0-60)	35	50
Elbow Extension (0)	11	20
Elbow Flexion (0-150)	121	95
Forearm Pronation (0-90)	60	75
Forearm Supination (0-90)	60	55
Wrist Flexion (0-80)	65	50
Wrist Extension (0-70)	45	45
Radial Deviation (0-20)	30	12
Ulnar Deviation (0-30)	25	25

(Grip)

	Left Hand	Right Hand
Average Grip	79.2667	75.1333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	12.2	13.3333

Group 1 Post-Measurements (Play-Based Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	160	180
Shoulder Extension (0-60)	80	75
Shoulder Abduction (0-180)	180	180
Shoulder External Rotation (0-90)	55	85
Shoulder Internal Rotation (0-60)	45	55
Elbow Extension (0)	0	0
Elbow Flexion (0-150)	120	155
Forearm Pronation (0-90)	90	90
Forearm Supination (0-90)	75	90
Wrist Flexion (0-80)	30	60
Wrist Extension (0-70)	45	45
Radial Deviation (0-20)	35	20

Ulnar Deviation (0-30)	20	20

(Grip)

	Left Hand	Right Hand
Average Grip	64.2	70.43

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	12.37	16.63

Group 1 Pre-Measurements (Play-Based Exercises)

Participant # 19

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	129	145
Shoulder Extension (0-60)	79	34
Shoulder Abduction (0-180)	143	144
Shoulder External Rotation (0-90)	90	89
Shoulder Internal Rotation (0-60)	10	65
Elbow Extension (0)	5	3
Elbow Flexion (0-150)	96	82
Forearm Pronation (0-90)	57	65
Forearm Supination (0-90)	70	85
Wrist Flexion (0-80)	50	75
Wrist Extension (0-70)	57	50
Radial Deviation (0-20)	8	0
Ulnar Deviation (0-30)	30	30

(Grip)

	Left Hand	Right Hand
Average Grip	29.8333	28.0333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	12	15.0667

Group 1 Post-Measurements (Play-Based Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	155	161
Shoulder Extension (0-60)	80	79
Shoulder Abduction (0-180)	170	175
Shoulder External Rotation (0-90)	88	78
Shoulder Internal Rotation (0-60)	78	80
Elbow Extension (0)	3	4
Elbow Flexion (0-150)	141	135
Forearm Pronation (0-90)	60	45
Forearm Supination (0-90)	55	60
Wrist Flexion (0-80)	40	50
Wrist Extension (0-70)	80	77
Radial Deviation (0-20)	28	28
Ulnar Deviation (0-30)	45	40

(Grip)

	Left Hand	Right Hand
Average Grip	39.03	41.23

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	11.1	12.73

Group 2 Pre-Measurements (Therapeutic Exercise Exercises)

Participant # 20

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	145	170
Shoulder Extension (0-60)	87	70
Shoulder Abduction (0-180)	175	165
Shoulder External Rotation (0-90)	94	85

Shoulder Internal Rotation (0-60)	63	82
Elbow Extension (0)	5	0
Elbow Flexion (0-150)	121	140
Forearm Pronation (0-90)	60	80
Forearm Supination (0-90)	60	80
Wrist Flexion (0-80)	45	60
Wrist Extension (0-70)	40	62
Radial Deviation (0-20)	13	10
Ulnar Deviation (0-30)	30	35

(Grip)

	Left Hand	Right Hand
Average Grip	35.3333	35.6333

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	28.4	12.3333

Group 2 Post-Measurements (Therapeutic Exercise Exercises)

Range of Motion (ROM) and Grip/Lateral Pinch Strength Measurements

	Left Upper Extremity	Right Upper Extremity
Shoulder Forward Flexion (0-180)	160	155
Shoulder Extension (0-60)	65	85
Shoulder Abduction (0-180)	165	160
Shoulder External Rotation (0-90)	72	73
Shoulder Internal Rotation (0-60)	60	60
Elbow Extension (0)	10	10
Elbow Flexion (0-150)	140	135
Forearm Pronation (0-90)	65	75
Forearm Supination (0-90)	80	85
Wrist Flexion (0-80)	65	65
Wrist Extension (0-70)	55	65
Radial Deviation (0-20)	10	5
Ulnar Deviation (0-30)	25	30

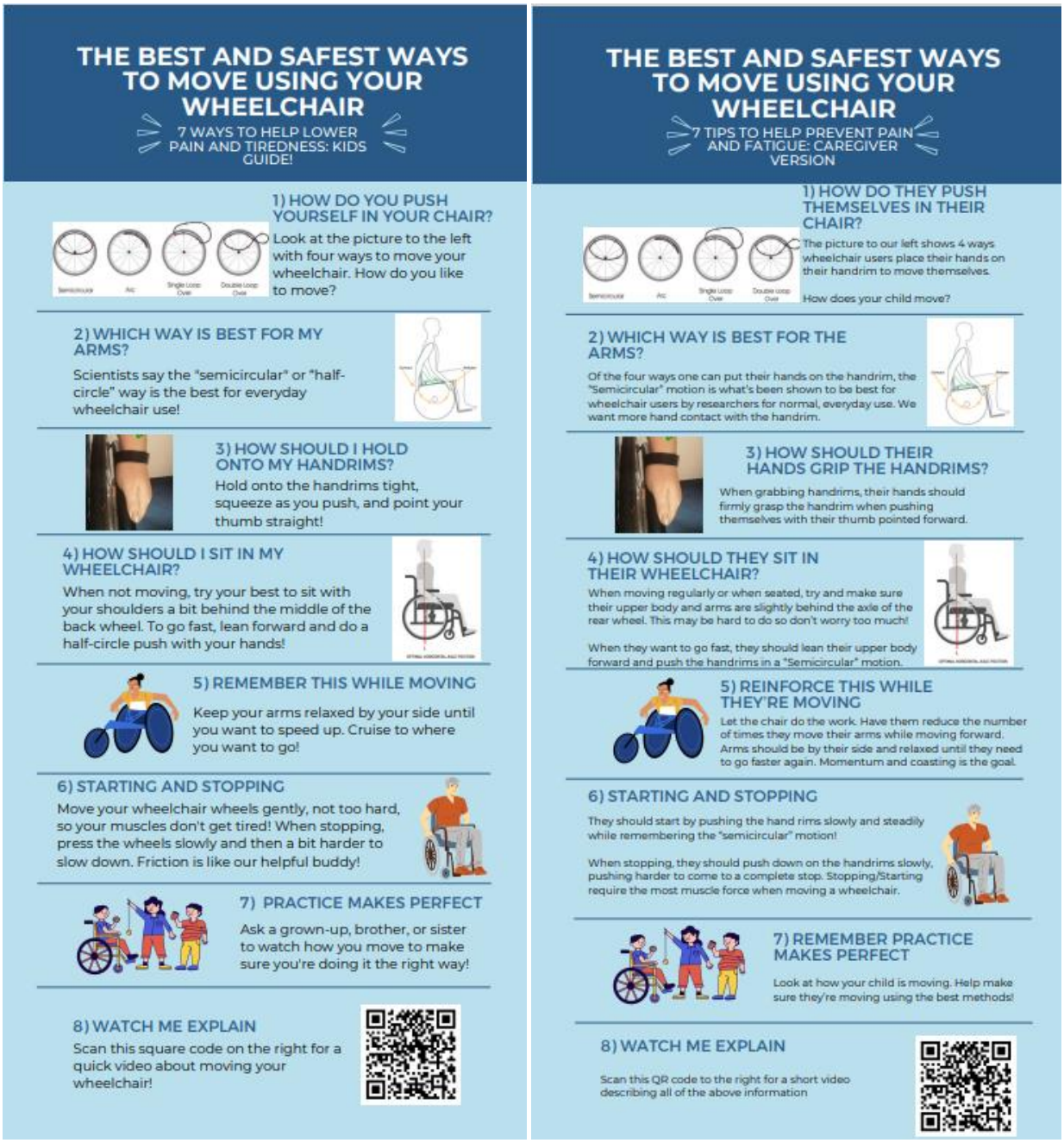
(Grip)

	Left Hand	Right Hand
Average Grip	41.1	34.7

(Lateral – Key Hold)

	Left Hand	Right Hand
Average Pinch	15.37	17.47

Appendix F



THE BEST AND SAFEST WAYS TO MOVE USING YOUR WHEELCHAIR

7 WAYS TO HELP LOWER PAIN AND TIREDNESS: KIDS GUIDE!

1) HOW DO YOU PUSH YOURSELF IN YOUR CHAIR?

Look at the picture to the left with four ways to move your wheelchair. How do you like to move?

2) WHICH WAY IS BEST FOR MY ARMS?

Scientists say the "semicircular" or "half-circle" way is the best for everyday wheelchair use!

3) HOW SHOULD I HOLD ONTO MY HANDRIMS?

Hold onto the handrims tight, squeeze as you push, and point your thumb straight!

4) HOW SHOULD I SIT IN MY WHEELCHAIR?

When not moving, try your best to sit with your shoulders a bit behind the middle of the back wheel. To go fast, lean forward and do a half-circle push with your hands!

5) REMEMBER THIS WHILE MOVING

Keep your arms relaxed by your side until you want to speed up. Cruise to where you want to go!

6) STARTING AND STOPPING

Move your wheelchair wheels gently, not too hard, so your muscles don't get tired! When stopping, press the wheels slowly and then a bit harder to slow down. Friction is like our helpful buddy!

7) PRACTICE MAKES PERFECT

Ask a grown-up, brother, or sister to watch how you move to make sure you're doing it the right way!

8) WATCH ME EXPLAIN

Scan this square code on the right for a quick video about moving your wheelchair!

THE BEST AND SAFEST WAYS TO MOVE USING YOUR WHEELCHAIR

7 TIPS TO HELP PREVENT PAIN AND FATIGUE: CAREGIVER VERSION

1) HOW DO THEY PUSH THEMSELVES IN THEIR CHAIR?

The picture to our left shows 4 ways wheelchair users place their hands on their handrim to move themselves.

How does your child move?

2) WHICH WAY IS BEST FOR THE ARMS?

Of the four ways one can put their hands on the handrim, the "Semicircular" motion is what's been shown to be best for wheelchair users by researchers for normal, everyday use. We want more hand contact with the handrim.

3) HOW SHOULD THEIR HANDS GRIP THE HANDRIMS?

When grabbing handrims, their hands should firmly grasp the handrim when pushing themselves with their thumb pointed forward.

4) HOW SHOULD THEY SIT IN THEIR WHEELCHAIR?

When moving regularly or when seated, try and make sure their upper body and arms are slightly behind the axle of the rear wheel. This may be hard to do so don't worry too much!

When they want to go fast, they should lean their upper body forward and push the handrims in a "Semicircular" motion.

5) REINFORCE THIS WHILE THEY'RE MOVING

Let the chair do the work. Have them reduce the number of times they move their arms while moving forward. Arms should be by their side and relaxed until they need to go faster again. Momentum and coasting is the goal.

6) STARTING AND STOPPING

They should start by pushing the hand rims slowly and steadily while remembering the "semicircular" motion!

When stopping, they should push down on the handrims slowly, pushing harder to come to a complete stop. Stopping/Starting require the most muscle force when moving a wheelchair.

7) REMEMBER PRACTICE MAKES PERFECT

Look at how your child is moving. Help make sure they're moving using the best methods!

8) WATCH ME EXPLAIN

Scan this QR code to the right for a short video describing all of the above information

Appendix G

IU Skills on Wheels | Shoulder Pain Rating Tool

Participant Information

* indicates required question

1) Name *

2) Age *

3) Sex *

4) How many years have you been using a wheelchair? *

5) What kind of wheelchair do you use? *

6) What is your primary diagnosis? *

7) How many times do you get in and out of your wheelchair per day? *

8) Have you gotten a new wheelchair in the past year? *

9) Have you gone through a life-changing event in the past year? If so, what was it? *

10) Have you been taken to the hospital in the past year? If so, why and for how long? *

11) Have you had surgery in the past year? If so, what for? *

12) Have you gotten OT/PT in the past year? *

13) If you answered yes to question 12, are you still getting OT/PT?

14) If you answered yes to question 12, have you been taught wheelchair skills?

15) If you answered yes to question 12, have you worked on making your arm stronger?

16) If you answered no to question 12, why did you stop?

17) If you have shoulder pain, which shoulder is it in? *

18) If you answered yes to question 17, how long have you had shoulder pain?

19) Please put any more information that might be important to a change in how you move.

Next

Pediatric Wheelchair Users Functional Shoulder Pain Index

This assessment was created and formatted for completion by participants of Indiana University's Skills on Wheels program, assessing the impact of potential upper extremity pain on functional performance in a child's day-to-day life.

Upper Extremity Pain History

My shoulders have hurt while I've used a wheelchair.

Patient has not performed this in the past week

My shoulder hurts right now.

Patient has not performed this in the past week

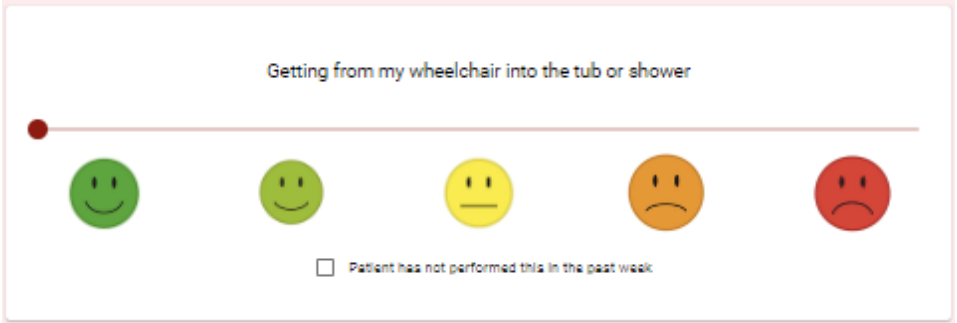
How long have you had shoulder pain?

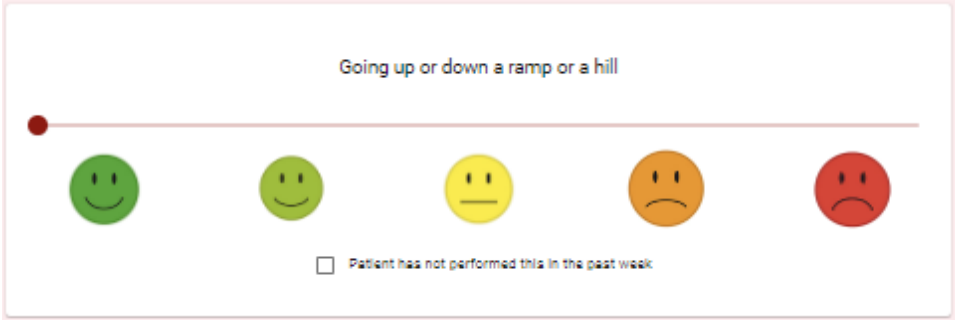
Patient has not performed this in the past week

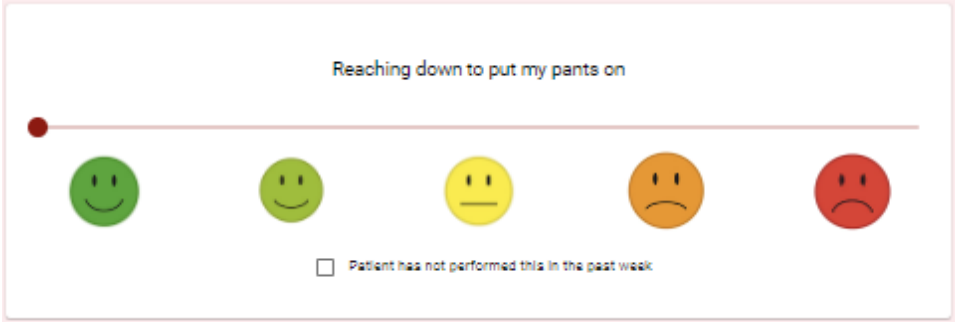
When my shoulder hurts, it makes me mad.

Patient has not performed this in the past week

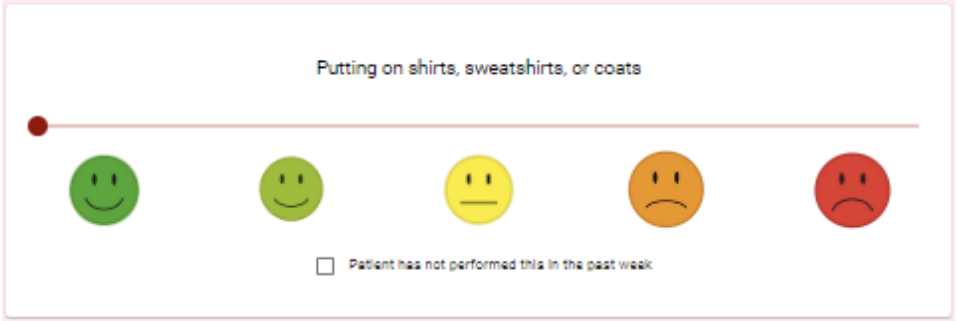

I wake up at night because my shoulder hurts.
Patient has not performed this in the past week
I can move my shoulders easily.
Patient has not performed this in the past week
My hands or elbows have hurt while I've been using a wheelchair.
Patient has not performed this in the past week
Moving
Getting out of my bed to my wheelchair
Patient has not performed this in the past week
Getting from my wheelchair into a car
Patient has not performed this in the past week

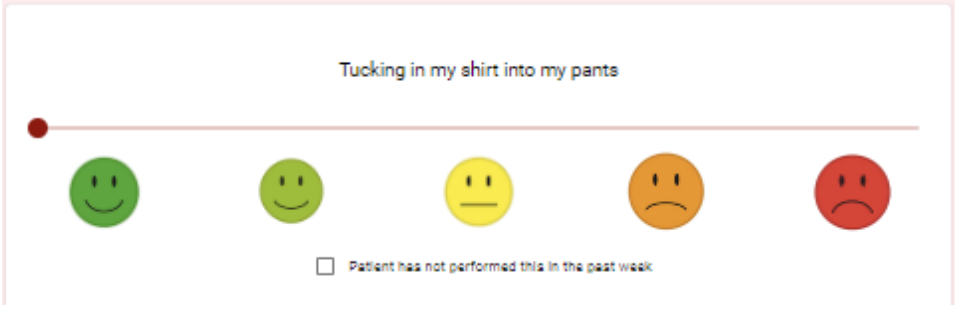

Getting from my wheelchair into the tub or shower
Patient has not performed this in the past week

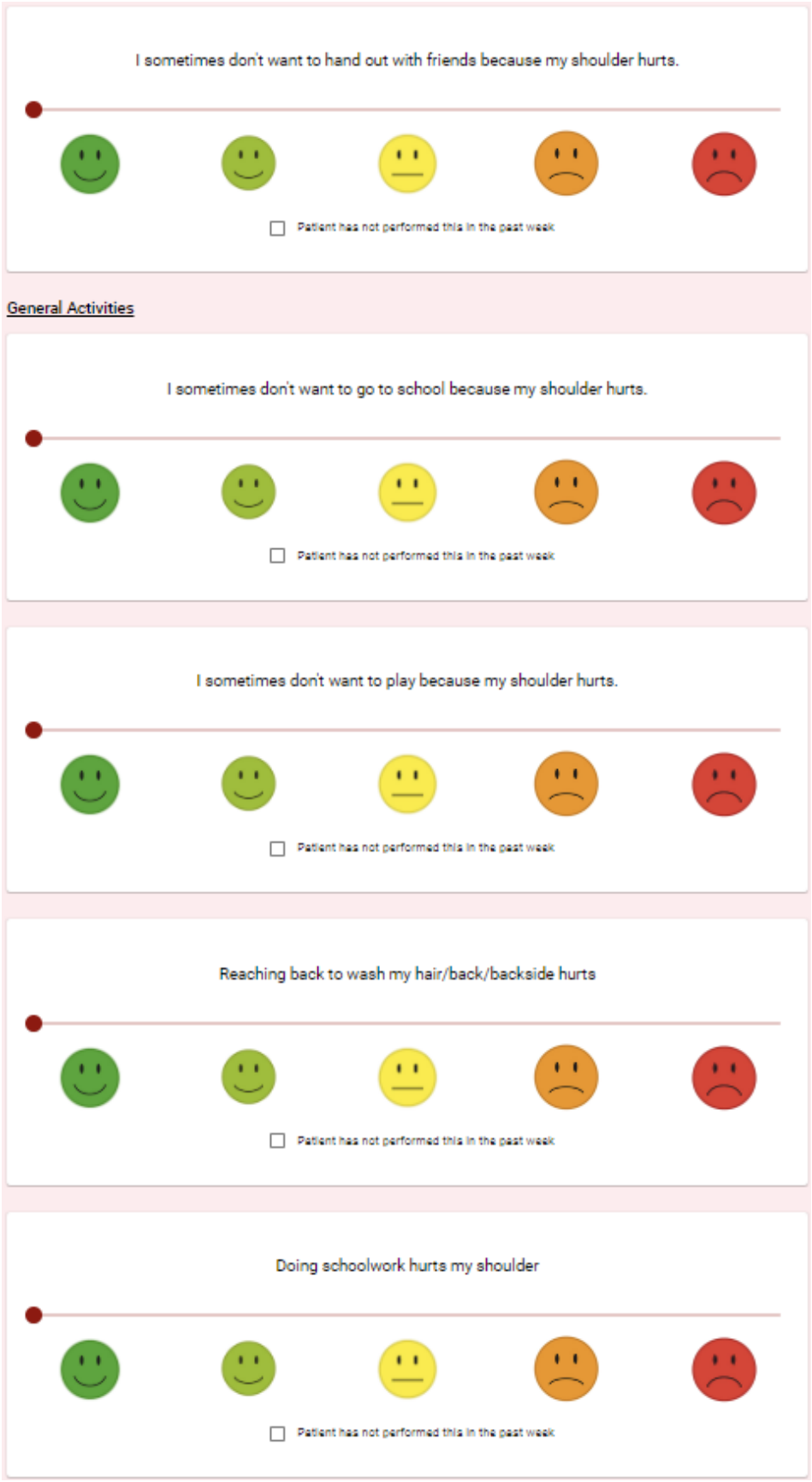

Going up or down a ramp or a hill
Patient has not performed this in the past week

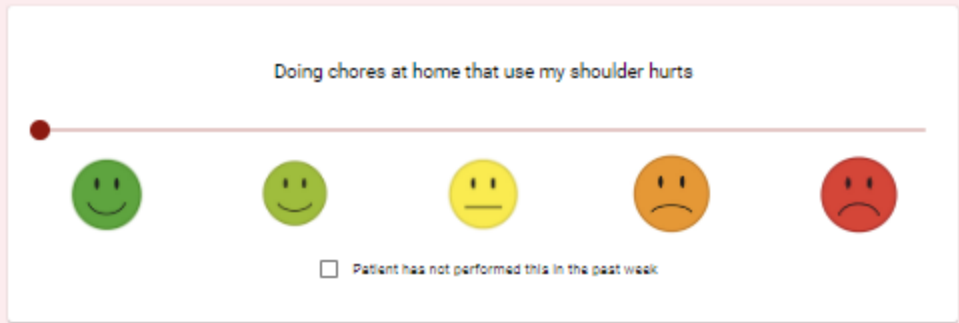

Reaching down to put my pants on
Patient has not performed this in the past week

Self-Care


Putting on shirts, sweatshirts, or coats
Patient has not performed this in the past week


Tucking in my shirt into my pants
Patient has not performed this in the past week


I sometimes don't want to hand out with friends because my shoulder hurts.
Patient has not performed this in the past week
General Activities
I sometimes don't want to go to school because my shoulder hurts.
Patient has not performed this in the past week
I sometimes don't want to play because my shoulder hurts.
Patient has not performed this in the past week
Reaching back to wash my hair/back/backside hurts
Patient has not performed this in the past week
Doing schoolwork hurts my shoulder
Patient has not performed this in the past week



Appendix H

1. On average, how many days of the week these past 5 weeks did your child perform the exercises in their assigned home exercise program (HEP)?
    a. *Create a slider that is from 0-7 with the top label being "Days Spent Exercising Weekly"*
2. Did you and/or your child see a benefit from completing the exercises during the 5 weeks of Skills on Wheels?
    a. Free Response
3. Have you noticed any changes in how your child propels from before the program to now? Explain if needed
    a. Free Response
4. Do you plan to continue to perform exercises and ensure best practices with propulsion after Skills on Wheels finishes?
    a. Multiple choice with 5 number of choices
        i. I did :
            1. Definitely Not
            2. Probably Not
            3. Might or might not
            4. Probably Yes
            5. Definitely Yes
5. Do you have any recommendations on how exercises in either HEP could be improved or propulsion training could be improved?
    a. Free Response