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Characterizing Pediatric Hand Grasps During Activities of Daily Living to Inform Robotic Rehabilitation and Assistive Technologies

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Abstract— **Hand function plays a critical role in how we interact with our physical environment. Hand motor impairments in children can compromise many facets of their daily life including physical independence and social interactions. For adults, there has been an emergence of mechatronic rehabilitation systems to improve hand mobility, strength, and dexterity; assistive technologies such as exoskeletons to drive impaired digits; and highly dexterous upper limb prostheses. Although similar devices are on the clinical horizon for children, childhood play, motor development, and daily activities mean they use their hands in fundamentally different ways than adults. It is imperative that devices for this population facilitate their unique needs; yet it is not completely known which hand movements may be of the highest priority during daily tasks or rehabilitation to best foster functional independence. Here, we evaluated and categorized the hand activity of two children in their home environments. Small wearable video cameras were attached to the children as they performed daily tasks and the video footage was analyzed to obtain the frequency and duration of their hand grasp movements. It was found that 7 common grasps accounted for 90% or greater of the children's hand activity in duration and frequency. This suggests, that like adults, a repertoire of common hand grasps may be prioritized by rehabilitative or assistive devices to ensure effective outcomes in performing daily activities.**

I. INTRODUCTION

Our hands play an important role in how we engage with the world around us. Our abilities to perform daily tasks, work-related functions, and many social interactions are largely influenced by our hand function. The importance is perhaps most strongly emphasized when hand function is chronically impaired, often compromising physical independence and reducing the quality of life for affected individuals [1]. In recent years advances in robotics and mechatronics have facilitated the development of numerous technological approaches to address challenges associated with impaired hand motor function. These include rehabilitation systems to improve hand mobility, strength, and dexterity [2], assistive technologies such as powered exoskeletons to drive impaired digits [3], [4], and even highly dexterous prostheses to provide a variety of grasping options when an upper limb is lost [5], [6].

For children, healthy hand and upper limb function are crucial not only to their independence [7], but to their physical development [8], and participation in social environments [9]. Much like the recent emergence of robotic rehabilitative and assistive devices for adults many similar technologies are on the clinical and research horizons for pediatric patients with hand motor impairments. However, the nature of childhood play and daily activities means that children use their hands in fundamentally different ways than adults. Further, as children develop so do their motor systems. Here, age-appropriate and activity-specific tasks are important considerations when developing treatment protocols for this unique population [10]–[12]. It is imperative that rehabilitative and assistive devices can facilitate these needs; yet there remains a knowledge gap in which hand grasps or movements may be of the highest priority during rehabilitation or daily tasks to provide the most effective outcomes and functional independence.

Hands have immense dexterity as they have the ability to move with up to 27 degrees of freedom and are actuated by more than 30 muscles [13]. Hand motor control relies on multiple inputs including proprioceptive and tactile sensory feedback [14] and may even be coordinated with the activity of the other hand during bimanual tasks. Even as robotic technologies advance and continue to be miniaturized, the most sophisticated robotic manipulators and rehab devices are still challenged to achieve the same levels of dexterity and control. Yet interestingly, in adults, it has been shown that we use a reduced repertoire of hand movements to achieve most daily tasks. This taxonomy of common movements can be simplified to 17 generalized configurations [15]. It has been further shown that in home and industrial settings 6-9 common grasps can account for nearly 80% of all hand activity with Wrap, Lateral Tripod, Lateral Pinch, and Tripod grasps being the top 4 most frequently used grasps among adults [15], [16].

Although currently, it may be impractical for rehabilitative and assistive devices to offer dexterity that rivals an intact healthy hand, it is feasible that significant functional gains may be provided. This can be done by targeting specific aspects of the motor impairment related to strategic grasping patterns and hand movements. Yet, unlike adults, a common pediatric hand grasp taxonomy has yet to be developed. This gap in knowledge presents barriers to making informed device design decisions that promote the overall effectiveness and function of newly emerging robotic devices offered to pediatric patients. The effectiveness of a device and resulting function are among the most important factors when considering user-based needs [14] and are driving factors influencing the adoption or abandonment of clinical technologies.

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The objective of this work was to explore how healthy able-bodied children use their hands in daily tasks and how this may differ from adult literature. We investigated two pediatric participants and characterized their hand grasping movements in a home environment. We evaluated the duration and frequency of hand grasps across their dominant and non-dominant sides. Further, we hypothesized that children would exhibit a unique set of grasps that may be different from those reported in adult literature as their motor systems are still developing and their daily activities differ from an adult.

II. METHODS

A. Participants

Two female children participated in this study. Research protocols were approved by the Institutional Review Board at the University of California, Davis. Participants provided written informed assent and their parents/legal guardians provided written informed consent. Participants PARC1 and PARC2 were 7 and 10 years old at the time of the study, respectively. Both participants had a dominant right hand with the same results of L.Q.= +100, Decile R.10 as determined by the Edinburgh Inventory [17]. Additionally, enrolment in this study required participants to be healthy with no neuromuscular or motor impairments that may impact hand or upper limb use.

B. Experimental Equipment

To record the participants' hand activities, a video camera was mounted to the child's head using an elastic strap harness (Fig.1). Guardians and participants were instructed on how to properly don the camera prior to data collection. A GoPro Hero5 video camera with a 1080 resolution at 60 frames per second (fps) was used with the field of view set to wide mode. This camera configuration was chosen due to its lightweight nature, large field of view, reduced invasiveness, and ease of data analysis. To ensure the video camera was recording at the correct angle to capture the child's action space, guardians observed the GoPro's video stream and adjusted the camera mount as necessary. Participants and guardians were instructed to record footage in the home environment during regular daily activities. They were encouraged to avoid recording daily events that would result in long periods of hand inactivity such as watching television, resting, or sleeping. Approximately 2 hours of video data were obtained for each participant over the course of 2-3 days. It was confirmed by the guardians that wearing the camera resulted in no noticeable changes in daily activity performed by the children.

C. Analysis and Procedures

To categorize hand activity from the video footage, we adopted previously defined grasp taxonomies from *Feix et al.* Consistent with their work, we simplified the total number of hand grasps to 17 generalized configurations [15]. We then broke down grasps into three main categories power, intermediate, and precision [15]. We further separated grasps based on digit opposition and defined a 'virtual finger' when multiple digits actuated together [15]. The final inventory upon which hand movements were classified is depicted in Fig. 2. Our adopted grasp taxonomy includes the frequency and duration in which hand grasps were used irrespective of

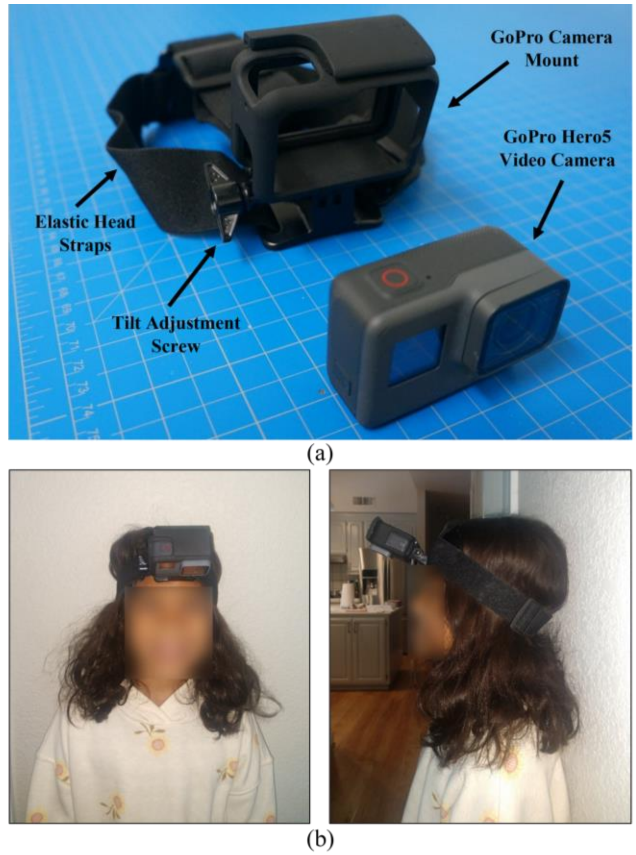


Figure 1. Video camera harnessing equipment and setup. (a) The elastic strap allows for comfortable and adjustable mounting. GoPro Hero5 is attached to the camera mount which allows for angled tilt adjustment. (b) Depicts a front and side view of the camera setup worn by a participant.

object shape and size [15]. This definition is relevant within the context of rehabilitative and assistive devices, as they are often programmed to achieve digit actuation from a fully extended to a flexed position rather than intermediate degrees of digit movement for individual objects that may be manipulated.

Using the grasping movements depicted in Fig. 2, video footage was manually reviewed to classify the hand grasping movements of participants. Two raters were trained to recognize and classify hand grasp data from the footage. Further, in conjunction with the generalized grasp taxonomy we adopted and for clarity, raters used a reference of supplemental material depicting grasps in everyday scenarios [18]. Prior to video analysis, a grasp inclusion/exclusion methodology was determined as follows:

- Grasps that were in the video frame and clearly distinguishable were readily classified.
- Open hand configurations were not considered grasps.
- Any hand movements that were not clearly identifiable were reviewed by 2 raters who came to a consensus on the grasp. In the unlikely event, the grasp was unidentifiable it was flagged and not tabulated.
- Grasps that were covered by obstacles and/or poor video resolution were not tabulated.

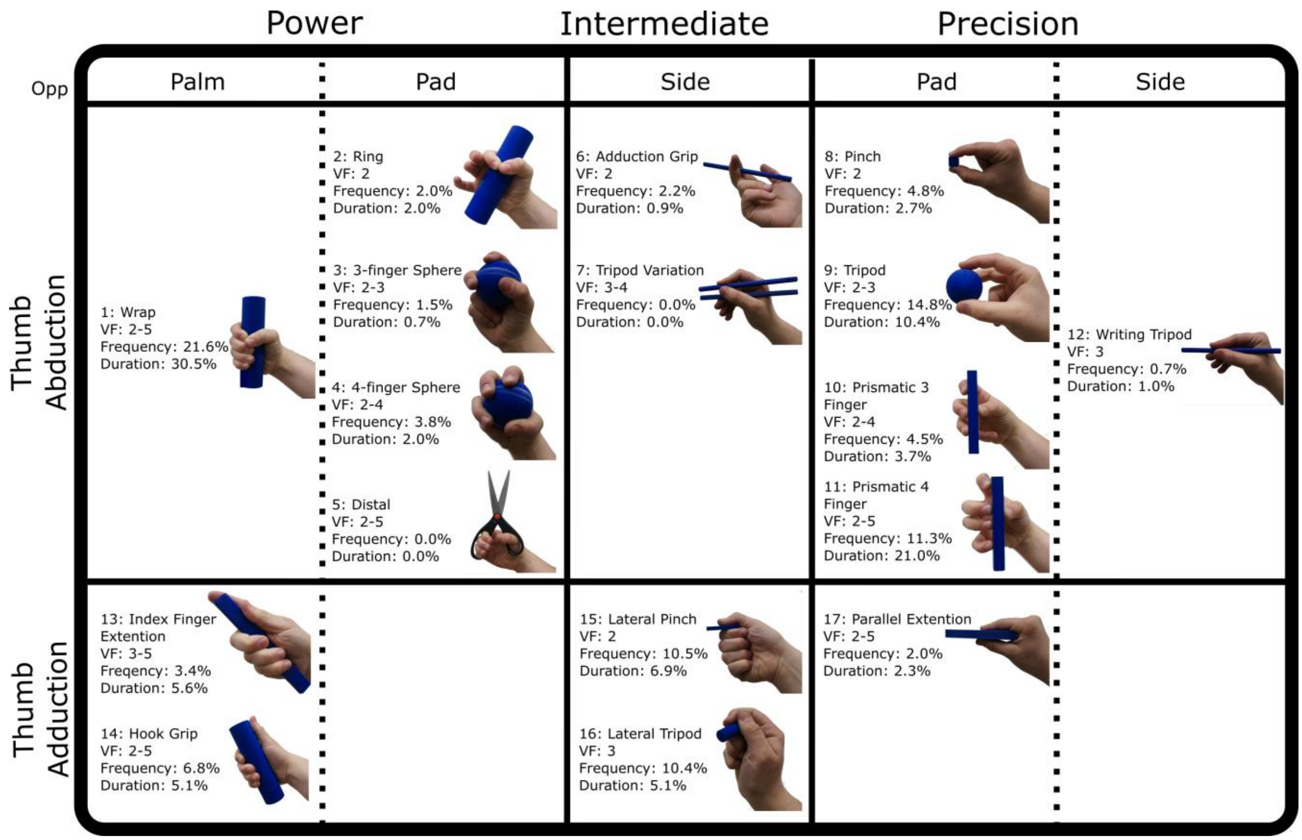


Figure 2. Adult generalized hand grasps reported in and adapted from [15]. Grasps presented are irrespective of object shape and size. Grasps are defined by three categories, power, intermediate, and precision. They are further broken down by opposition (Opp) type and a virtual finger (VF). The generalized percent grasp frequency and duration for adults are tabulated.

Video data were analyzed using the VSDC Video Editor (*Flash-Integro LLC*) software allowing for frame-by-frame playback. A similar study using two raters has shown such rating methods to achieve high inter-rater agreement with minor inconsistencies [19]. Raters tabulated video data in a shared spreadsheet that included grasp identification, side of hand use, the beginning and ending frames, and any additional notes. Finally, to analyze the tabulated data, a MATLAB (The MathWorks, Inc.) script was written to extract the duration and frequency along with their corresponding percentages for participants' dominant and non-dominant hands.

We analyzed the data by assigning a grasp identification number from 1 to 17 corresponding to the generalized grasps in Fig. 2. The duration of a grasp was calculated using the difference between the corresponding beginning and ending frame number and converting this value to seconds by dividing by the frame rate (60 fps). Duration was defined as the time a grasp was held, which began once the hand was securely holding an object and ended at the onset of release. The total duration of a specific grasp was calculated by summing the duration times, and its percent duration was defined by the ratio of a specific grasp's total duration to the total duration of all grasps [16]. The duration and percent duration were calculated for both the dominant and non-dominant hands. Furthermore, data included grasp frequency, the number of times a grasp was performed by the participant, which was further separated by hand dominance. The percent frequency was obtained for each grasp by the ratio of a single grasp's frequency to that of the total instances all grasps were used [16].

III. Results

A. PARC1

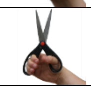
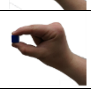
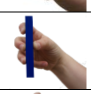
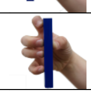
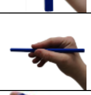
PARC1 used their hands to manipulate objects related to drawing/coloring, turning book pages, and retrieving food from a refrigerator, among many other activities. Of the more than 120 minutes of footage obtained, an aggregate of 107 minutes captured the participant using either their dominant or non-dominant hand performing grasps. Out of the 107 active minutes, the child used their dominant and non-dominant hand for approximately 91 and 16 minutes, respectively. The total number of performed grasps was 1115 with 696 from the dominant hand and 419 from the non-dominant hand. The duration and frequency of individual grasps according to hand dominance along with their percentage are given in Table I.

When combining the dominant and non-dominant hands it was found that 90% of the time the child frequently used a set of seven generalized grasp configurations. Additionally, over 90% of the duration could be accounted for by these same seven grasps. Interestingly, it was found that 74% of the duration was attributed to a single generalized grasp, Tripod. However, this same grasp only accounted for 30% of the total grasp frequency. Fig. 3a displays the total combined grasp frequency and Fig. 3b displays the total combined grasp duration.

B. PARC2

Data were obtained from analyzing approximately 132 minutes of video footage in which the child used their hands

TABLE I. PARTICIPANT GRASP DURATION AND FREQUENCY

ID	Grasp	PARC1 Hand				PARC2 Hand			
		Dominant		*Nondominant*		*Dominant*		*Nondominant*	
		Duration (%)	*Frequency (%)*	*Duration (%)*	*Frequency (%)*	*Duration (%)*	*Frequency (%)*	*Duration (%)*	*Frequency (%)*
1		106 (1.9)	54 (7.8)	295 (30.4)	26 (6.2)	205 (5.8)	51 (6.9)	224 (6.6)	66 (10.6)
2		0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	10 (0.3)	3 (0.4)	0 (0.0)	0 (0.0)
3		0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	49 (1.4)	3 (0.4)	8 (0.2)	4 (0.6)
4		111 (2.0)	42 (6.0)	222 (22.8)	70 (16.7)	79 (2.2)	23 (3.1)	59 (1.8)	23 (3.7)
5		0 (0.0)	0 (0.0)	6 (0.6)	5 (1.2)	110 (3.1)	9 (1.2)	0 (0.0)	0 (0.0)
6		10 (0.2)	7 (1.0)	37 (3.8)	3 (0.7)	3 (0.1)	2 (0.3)	1 (0.0)	1 (0.2)
7		0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
8		117 (2.1)	120 (17.2)	44 (4.6)	45 (10.7)	903 (25.3)	221 (29.7)	1804 (53.4)	194 (31.2)
9		4739 (86.5)	300 (43.1)	37 (3.8)	29 (6.9)	1315 (36.8)	239 (32.1)	97 (2.9)	68 (10.9)
10		36 (0.7)	26 (3.7)	38 (3.9)	26 (6.2)	85 (2.4)	16 (2.2)	277 (8.2)	89 (14.3)
11		63 (1.2)	25 (3.6)	83 (8.5)	46 (11.0)	68 (1.9)	15 (2.0)	354 (10.5)	77 (12.4)
12		15 (0.3)	2 (0.3)	0 (0.0)	1 (0.2)	58 (1.6)	3 (0.4)	0 (0.0)	0 (0.0)
13		6 (0.1)	3 (0.4)	3 (0.3)	2 (0.5)	6 (0.2)	3 (0.4)	40 (1.2)	6 (1.0)
14		17 (0.3)	6 (0.9)	8 (0.9)	5 (1.2)	62 (1.7)	23 (3.1)	145 (4.3)	30 (4.8)
15		144 (2.6)	55 (7.9)	119 (12.2)	111 (26.5)	592 (16.6)	118 (15.9)	301 (8.9)	57 (9.2)
16		29 (0.5)	18 (2.6)	15 (1.5)	8 (1.9)	5 (0.2)	7 (0.9)	1 (0.0)	1 (0.2)
17		83 (1.5)	38 (5.5)	65 (6.7)	42 (10.0)	19 (0.5)	8 (1.1)	69 (2.0)	6 (1.0)

The table illustrates the grasp duration and frequency for both child participants. The grasp identification (ID) number followed by the grasp picture are displayed. Data presented were separated by participant, hand dominance, and broken into duration and frequency. The duration and frequency are defined as the time in seconds and total number of instances each grasp was performed, respectively. Additionally, the percentage of duration and frequency out of all the grasps performed are provided in the parenthesis.

to manipulate objects related to knitting, preparing hot chocolate, and playing with art supplies such as clay, among many other activities. There was a total of about 115 active minutes where the child performed grasps with either their dominant hand or non-dominant hand. Moreover, the participant used their dominant and non-dominant hand for approximately 59 and 56 minutes, respectively, out of the total active time. The number of performed grasps was 1366, exceeding the total of PARC1 by 251. Here, 744 were attributed to the dominant hand and 622 were from the non-dominant hand. Results from Table I show the compiled duration and frequency data for individual grasps based on hand dominance and their corresponding percentages.

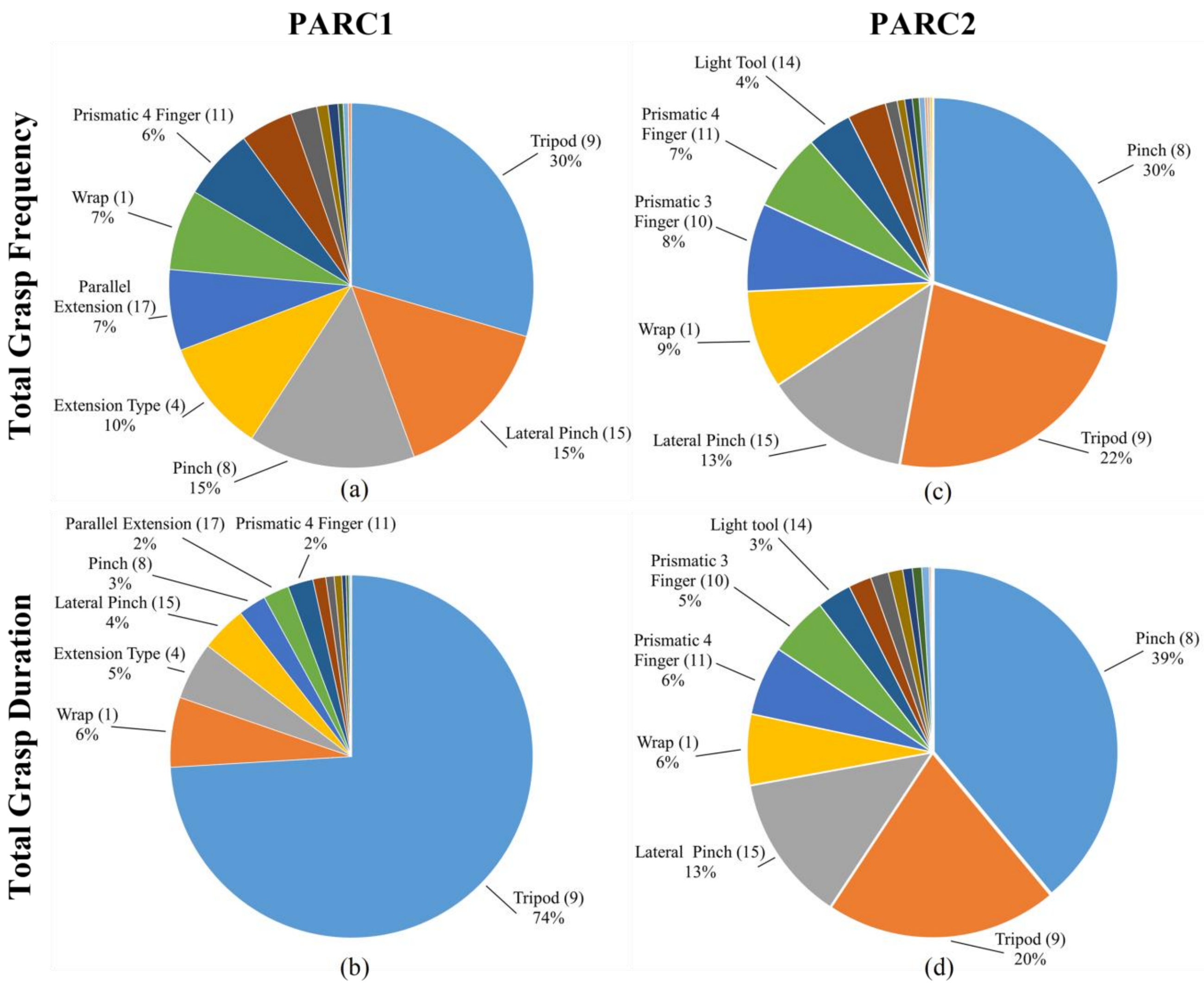


Figure 3. Pie charts of the combined dominant and non-dominant hand grasps depicting the frequency and duration for PARC1 and PARC2. (a) Depicts PARC1's combined total percent frequency with 90% of the total frequency accounted for by seven hand grasps. (b) PARC1's combined total percent duration where the same seven hand grasps attributed to 96% of the duration. (c) Illustrates PARC2's combined total percent frequency with 93% accounted for by seven hand grasp configurations. (d) PARC2's combined total percent duration with 92% of the duration attributed to the same seven hand grasps.

Data synthesized across hands indicated 7 generalized grasps that accounted for 93% of their frequency. Upon analysis of the duration, it was found that 92% could account for these same grasp configurations. Grasp frequency and duration were more homogenous across combined data than that of PARC1. Here, 65% and 72% of the grasp frequency and duration, respectively, can be attributed to Pinch, Tripod, and Lateral Tripod. Data can be seen in Fig. 3c and Fig. 3d.

IV. Discussion

A common set of hand grasps was obtained for each child as they performed their daily activities. Data from both PARC1 and PARC2 are in agreement with similar adult studies which suggested that 6-9 standard grasps can account for nearly 80% of common activities [16]. Here 7 generalized grasps accounted for 90% or more of daily activities in both frequency and duration across both participants when handedness was not considered. This high percentage supports that a strategic repertoire of grasp configurations may be pertinent when developing rehabilitative and assistive devices.

For PARC1 the dominant hand accounted for about 85% of the total grasp duration yet the frequency of the dominant and non-dominant hands were approximately 62% and 38%, respectively. Further, PARC2's dominant and non-dominant hands accounted for 51% and 49% of the total grasp duration, respectively while the frequency of use was 54% for the dominant and 46% for the non-dominant. Even though the frequency and duration of the non-dominant hands are generally lower than that of the dominant hands, results suggest they still play a vital role in supporting everyday object interactions. These results further emphasize the importance of understanding the role both hands play when developing rehabilitative and assistive devices. For example, in populations of children with unilateral motor impairments, the unaffected side often assumes the dominant role while the affected side offers support and stabilization of objects. Therefore, it is critical to recognize how laterality may impact the desired function a patient wishes to accomplish with a robotic technology. Those with unilateral impairments may have very different demands than those affected bilaterally.

Interestingly, the results from both participants share the same top 3 frequently used generalized grasp configurations, Pinch, Lateral Pinch, and Tripod. These 3 grasps can be found within the top 7 generalized grasps used by adults and account for approximately 80% of their frequency [15]. Intriguingly, PARC1 performed 5 out of the 7 generalized grasps, and PARC2 performed 6 out of the 7. It was expected that children may use a variety of hand grasps to accomplish tasks. Although our limited data set of two children exhibited similarities to how adults use their hands, this may not be entirely representative of the whole pediatric population. Our data supports that a common repertoire of grasp configurations accounts for much of a child's hand activity and further investigation with a larger sample size across ages and sexes is warranted.

While limited, the data collected here suggests that as robotic rehabilitative and assistive technologies continue to emerge for children, consideration of key hand grasping movements will be vital to their effectiveness. For example, the current standard of care pediatric upper limb prostheses typically provides a single degree-of-freedom tripod grasp. This aligns well with PARC1's data in which a tripod grasp accounted for 74% total duration of hand use. However, PARC1's frequency data, shows 4 hand grasp types are needed to achieve 70% of the total grasp frequency. Thus, evaluating the effectiveness of mechatronic assistive devices requires data-rich approaches that account for both the frequency and duration of grasp type in real-world settings.

V. Conclusion and Future Work

This study explored how two children used their hands in daily activities and if they are inclined to use a strategic set of grasp patterns. It was found that 7 unique grasp configurations accounted for the vast majority of hand use in both frequency and duration across participants. Taken together, these results lay the foundation to further understand the stereotypical hand activity of children. Further, this work may help inform the development and evaluation of pediatric rehabilitative and assistive devices. However, there are a few limitations and future directions that must first be considered. A larger sample size is currently under investigation and will allow us to understand how hand grasps differ across age ranges, sexes, and daily activities. Moreover, due to the categorical nature of the generalized grasp taxonomy, additional data analysis can be achieved including analyses of digit opposition type, and virtual finger units among many others. Linking the activities the children performed to grasps may also provide a more comprehensive picture of hand use during specific activities of daily living. This may also include expanding the study environment beyond the home to social, school, and childcare settings.

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