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Original Research

Hand Use and Grasp Sensor System in Monitoring Infant Fine Motor Development

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Infant;
Play and playthings;
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Abstract *Objective:* To assess the feasibility of a hand use and grasp sensor system in collecting and quantifying fine motor development longitudinally in an infant's home environment.
Design: Cohort study. Researchers made home visits monthly to participating families to collect grasp data from infants using a hand use and grasp sensor.
Setting: Data collection were conducted in each participant's home.
Participants: A convenience sample of 14 typical developmental infants were enrolled from 3 months to 9 months of age. Two infants dropped out. A total of 62 testing sessions involving 12 infants were available for analysis (N=12).
Interventions: At each session, the infant was seated in a standardized infant seat. Each instrumented toy was hung on the hand use and grasp sensor structure, presented for 6 minutes in 3 feedback modes: visual, auditory, and vibratory.
Main Outcome Measures: Infant grasp frequency and duration, peak grasping force, average grasping force, force coefficient of variation, and proportion of bimanual grasps.
Results: A total of 2832 recorded grasp events from 12 infants were analyzed. In linear mixed-effects model analysis, when interacting with each toy, infants' peak grasp force, average grasp

List of abbreviations: CP, cerebral palsy; CV, coefficient of variance; GMA, General Movements Assessment.
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force, and accumulated grasp time all increased significantly with age (all $P<.001$). Bimanual grasps also occupied an increasingly greater percentage of infants' total grasps as they grew older (bar toy $P<.001$, candy toy $P=.021$).

Conclusions: We observed significant changes in hand use and grasp sensor outcome measures with age that are consistent with maturation of grasp skills. We envision the evolution of hand use and grasp sensor technology into an inexpensive and convenient tool to track infant grasp development for early detection of possible developmental delay and/or cerebral palsy as a supplement to clinical evaluations.

Various types of perinatal brain injury can result in neuromotor delay during infancy. Conditions such as periventricular leukomalacia, peri- or intraventricular hemorrhage, perinatal stroke, and migration abnormalities put infants at risk for movement and other disabilities as they grow and develop.[1] Since last appraised in 2013, global prevalence of cerebral palsy (CP) was holding steady at 2.11 per 1000 births,[2] making it the most common neuromotor disorder affecting children worldwide. A 10-year chart review of children with CP found that the mean age at diagnosis had been 13.6 months when referred by a medical specialist and 28.8 months when referred by a primary care provider, with referrals for rehabilitation (therapy) showing similar delays.[3]

By the end of the 20th century, recognition of the importance of environmental interactions in shaping motor skills emerged, and the role of sensory-motor experience along the developmental trajectory became a focus of exploration.[4] Today, it is believed that both neuromaturation and experiential learning are essential components in human motor skill acquisition.

Hand use in the first year of life is sensitive to sensory-motor experience, and studies showed that the haptic features of objects influence an infant's grasping patterns, and this influence changes with the infant's age (ie, phase of motor development),[5-8] which suggest a critical age window when infants' perceptual-motor processing skills are most strongly affected by sensory feedback during grasping. There is a growing understanding that activity-dependent plasticity in motor pathways has the potential to alter the course of neural development after early brain injury, calling for early rehabilitation interventions.[7,8] Furthermore, the first year of life sees a high rate of developmental change,[9] which can be exploited to make advances in functional hand use.

Consequently, deviations from the typical course of hand motor skill development should be detected as early as possible so that interventions can leverage the greater neuroplasticity that presents in the first year after birth.[10] In the case of CP, clinician confidence in making an early diagnosis is impeded by the lack of specific biomarkers of the disorder and by the difficulty of recognizing patterns that clinically describe CP[11] from those that signal typically developing variations.[12] Neuromotor maturation is assessed in infants through structured observation[13] of their general movements: spontaneous, circular, "fidgety" movements characterized by small amplitude, moderate speed, and variable acceleration of all limbs in all directions.[14] Future motor disability has been successfully predicted using a General Movements Assessment (GMA) instrument during the first year of life.[13] Notably, widely used clinical assessment tools such as the GMA are observation-based, require extensive training to perform effectively, and rely on categorical or ordinal scales that ultimately provide only limited resolution on the often subtle motor behaviors they evaluate.[15] There is no complementary, predictive assessment currently available that focuses on the interactive aspect of neurodevelopment in infancy such as might be observed from infants' routine, day-to-day manipulation of objects in their home environments. Such a longitudinal profile would be helpful in differentiating typical from delayed or atypical patterns of neuromotor skill acquisition.

Technology-enhanced assessment has the potential to improve on the measurement precision of observation-based tools and, in the process, produce a large body of normative data to increase knowledge of hand neuromotor development generally. For the past near-decade, the greater part of infant neuromotor sensing technology research has focused on detecting and analyzing patterns of movement, measuring, and modeling the same phenomena as the GMA.[16-22] The CareToy EU Project that produced an "intelligent baby gym" for home use with infants at risk for neurodevelopmental disorders is the most extensive example of this line of research and development.[18,19,23,24]

An ancillary stream of technology development focuses on quantifying and interpreting patterns of grasp forces infants generate as they develop neurologically after birth. These forces are measured through sensors embedded in toys designed to be visually attractive to infants and shaped to fit easily within their hands.[16-22] The CareToy uses sensorized toys for measuring grip force as part of a home-based baby gym for treatment and assessment of infants at risk of delay.[23] Sgandurra et al used CareToy to examine typically developing infants with sensorized toys from 18-41 weeks and found an increase in power grip force between 18 and 30 weeks of age followed by a plateau period.[24] Grasp force can potentially provide objective measurements of developmental status in a variety of populations.[25-27] To our knowledge, no group has used grasp force developmental trajectories to identify infants at risk for development delays.

The purpose of this pilot study is to explore (1) the feasibility of a hand use and grasp sensor system in collecting and quantifying grasp data longitudinally in an infant's home environment and (2) the variation in grasp-related hand use and grasp sensor outcome measures generated by typically developing infants from 3-9 months of age.

Methods

Hand use and grasp sensor system

The hand use and grasp sensor system was designed to measure infant fine motor development in the home environment.[20] Hand use and grasp sensor deployed 2 interchangeable instrumented toys, the bar toy (diameter=14mm and 17mm for babies 3-5 months old and 6-9 months old, respectively) and the candy toy (diameter=21.5mm), which were suspended on an adjustable flange attached to an A-frame and positioned over the infant (fig 1A).[28] When infants touched or manipulated a toy, their grasp force was detected by multiple force sensing resistors[29] embedded in the toy. An Arduino R3 microcontroller[a] was used to power the force-sensing resistors,[b] log grasp forces to a secure digital card,[c] and deliver visual, auditory, or tactile/vibratory feedback when infants grasped the toys (see fig 1B). The microcontroller and associated electronics were housed in a box equipped with a switch that parents or researchers used to initiate data collection and select visual, auditory, or vibratory feedback modes. A battery-operated mini camera[30,d] documented all infant interactions with a hand use and grasp sensor. Presentation configuration, proportion, color, and texture of fabric covers were selected in consultation with clinicians and iteratively modified based on observation of infants and feedback from parents in the early stage of the pilot prior to formal data collection.[20,31]

Participants

Fourteen infants were enrolled in this study from July 2019 to March 2020. Criteria for inclusion were (1) infant gestation of 37-42 weeks, (2) no complications during mother's pregnancy and delivery, and (3) infant age 12-36 weeks and parental age older than 18 years at time of enrollment. Infants were excluded from the study if the infant had any known genetic or neurologic conditions by parent report. Ethics approval for the hand use and grasp sensor study was obtained from the Institutional Review Board of the Catholic University of America, Washington, DC. Written informed consent was obtained from one of a participating infant's parents prior to installation of hand use and grasp sensor in the home and subsequent testing and data collection. Two infants dropped out of the study prior to data collection owing to the parents' difficulties in reserving time for this study. Ten testing sessions planned across 6 participants were curtailed by Institutional Review Board because of risks associated with the COVID-19 pandemic that emerged in the later months of the study. In all, a total of 62 testing sessions involving 12 infants were available for analysis (table 1).

Procedure

Researchers made home visits monthly to participating families to collect grasp data from infants using a hand use and grasp sensor. At each session, the infant was seated in a standardized infant seat in semirecline position with a safety seat belt buckled at the infant's lap. Each instrumented toy was hung on the structure in succession and adjusted to the participant's chest level (see fig 1B). Each toy was presented at the midline for 6 minutes in each of the 3 feedback modes: visual, auditory, and vibratory, in a randomized order. Green light embedded in the toys will light up for visual mode (see fig 1), the Twinkle Little Star and Lightly Row songs will loop alternately for auditory mode, and toys start vibration for vibratory mode. Each feedback was proportional to the detected grasping force. If infants did not initiate the first grasp on the hand use and grasp sensor toy spontaneously, after a few moments the researcher or parent would guide the infants' hands into contact with the toy.

Measurements

Forces applied to instrumented toy surfaces were sampled at 30 Hz, digitized, timestamped, converted to grams, and written to the hand use and grasp sensor system log. Grasp frequency and duration, peak grasping force, average grasping force, and the coefficient of variation (SD of the grasping

Table 1 Participants and data points

		Age (mo)						
Participant ID	Sex	3	4	5	6	7	8	9
P01	F			×	×	×	×	×
P02	F				×		×	×
P03	M				×	×	×	×
P04	F				×	×	×	×
P05	M	×	×	×	×	×	×	×
P05	F	×	×	×	×	×	×	
P07	F	×	×	×	×	×	×	×
P08	F	×	×	×	×	×	×	
P09	F	×	×	×	×	×	×	
P10	F	×	×	×	×	×	×	
P11	M	×	×	×	×			
P12	M	×	×	×	×			

Abbreviations: F, female; M, male.

force normalized by mean force, coefficient of variation [CV]) were calculated in MATLAB 2020a.[32,e]

Each qualified grasp event was coded as unimanual (force was exerted by only 1 hand) or bimanual (both hands were grasping the toy simultaneously). In the case of the bar toy, the location on the bar that the grasp took place was identified by inside, middle, or outside location. Midline crossing grasps that occurred on the bar toy were also recorded (see fig 1C). This coding was used to calculate the percentages of bimanual grasp, inside, middle, and outside bar grasps and the midline crossing grasps for each 2-minute trial.

To assess asymmetry, right hand ratios (R-ratios) were calculated for each outcome by dividing the right hand outcome by the right hand outcome plus the left hand outcome.

Statistical analysis

Q1 and Q3 are the first and third quartile, respectively (IQR=Q3−Q1). For grasping force related outcome measures, values above Q3+3 × IQR or below Q1−3 × IQR were considered as outliers and removed from the data set.

A linear mixed-effects model was selected for data analysis[33-35] using SPSS version 25.0.[f] The model included participants as the random effect. The model included age, toy type (bar toy and candy toy), and feedback mode (vibration, light, sound) as fixed effects, as well as the age × toy and age × mode interactions. Age was treated as a continuous covariate. We used random intercepts effect model. The "variance components" setting was used for the Covariance Type in SPSS, which assigns a scaled identity structure to each of the specified random effects. Dependent variables included in the analysis were the peak force, mean force, accumulated grasping time, total number of grasps, and force CV for each grasp. If an interaction effect was significant, additional mixed-effects model analysis on separate levels of the involved factors were conducted.

For the bar toy, additional tests were done on participants' grasping locations on the bar toy. The models included age and feedback mode as fixed effects as well as the age × mode interaction. The other model settings were kept the same.

Another linear mixed-effects model was used to assess the asymmetry of use of participants' hands. Dependent variables included the R-ratio for the peak force, mean force, grasping frequency, and accumulated grasping time.

The means ± SDs and confidence intervals were calculated based on the collected data. Loess smoothing method with 95% confidence intervals was also used in figs.

Results

A total of 2832 recorded grasp events from 12 infants were analyzed during this study, from which 24 grasp events were identified as outliers and removed from the data set (table 2). Toy type showed a significant effect on peak grasp force ($F_{1,341.301}$=9.060, P=.002, bar toy 926.0±41.6g, candy toy 326.0±42.1g) (fig 2A), force CV ($F_{1,341.456}$=23.995, P<.001, bar toy 0.535±0.019, candy toy 0.388±0.019) (see fig 2C), and accumulated grasp time ($F_{1,324.577}$=8.057, P=.005, bar toy 58.6±5.0 seconds, candy toy 24.6±5.1 seconds) (see fig 2D). Neither the toy feedback mode nor the age × feedback interaction were significant.

The toy × age interactions were significant for peak grasp force ($F_{1,341.155}$=4.627, P=.032), average grasp force ($F_{1,341.680}$=6.177, P=.013), force CV ($F_{1,340.981}$=10.399, P=.001), and percentage of bimanual grasps ($F_{1,343.911}$=6.189, P=.013). Thus, we analyzed the age effect for the bar toy and the candy toy separately for these 4 outcome measures.

When interacting with the bar toy, infants' peak grasp force (slope=71.841, $F_{1,183.039}$=17.674, P<.001) (see Fig 2A) and average grasp force (slope=21.299, $F_{1,179.347}$=19.144, P<.001) (see fig 2B) increased significantly with age. Bimanual grasps occupied an increasingly greater percentage of infants' total grasps as they got older (slope=0.033, $F_{1,146.855}$=21.945, P<.001) (see fig 2E). Most participants started to show the bimanual grasps as early as 3-4 months old. Force CV declined significantly with age (slope=−0.045, $F_{1,141.766}$=15.215, P<.001) (see fig 2C). The exemplary change in grasp force trajectory in a single participant is shown in fig 3.

When interacting with the candy toy, age showed significant effects on infant peak grasp force (slope=35.867, $F_{1,167.131}$=17.927, P<.001) (see fig 2A), average grasp force (slope = 7.167, $F_{1,150.859}$=13.057, P<.001, Fig 2b), and percentage of bimanual grasps (slope=0.015, $F_{1,151.635}$=5.403, P=.021) (see fig 2E).

Age showed a significant main effect on the accumulated grasp time (slope=3.165, $F_{1,353.997}$=26.530, P<.001) (see fig 2E) for both the bar toy and the candy toy. Regarding the grasp locations on the bar toy, age also showed a significant main effect on the percentage of grasps at the middle portion of the bar (slope=−0.056, $F_{1,178.372}$=9.060, P=.003), percentage of grasps at outside of the bar (slope=0.049, $F_{1,176.992}$=4.227, P=.041), and percentage of midline crossing grasps (slope=0.041, $F_{1,159.340}$=11.856, P=.001).

Analysis of R-ratios for the peak force, mean force, grasp frequency, and accumulated grasp time showed that the toy type and the toy × age interaction were not significant. When interacting with both toys, infants' R-ratios for peak grasp force (slope=−0.036, $F_{1,263.809}$=26.387, P<.001), mean force (slope=−0.026, $F_{1,254.072}$=14.612, P<.001), grasp frequency (slope=−0.036, $F_{1,337.445}$=10.716, P=.001), and accumulated grasp time (slope=−0.051, $F_{1,347.018}$=19.263, P<.001) all decreased significantly with age.

Discussion

This study assessed the feasibility of a hand use and grasp sensor system and demonstrated a statistically significant relationship between the outcome measures derived from hand use and grasp sensor engagement and infants' age. The results indicated the feasibility and the potential to use these measures clinically as indicators for infants' normative neurodevelopment. In this exploratory study, we took the first steps in determining whether a grasp measurement system such as hand use and grasp sensor can detect changes in actual reach to grasp and fine motor movement abilities that occur over developmental stages.

When interacting with the bar toy, as participants got older, results (see fig 2, Table 2, and supplemental data S1)

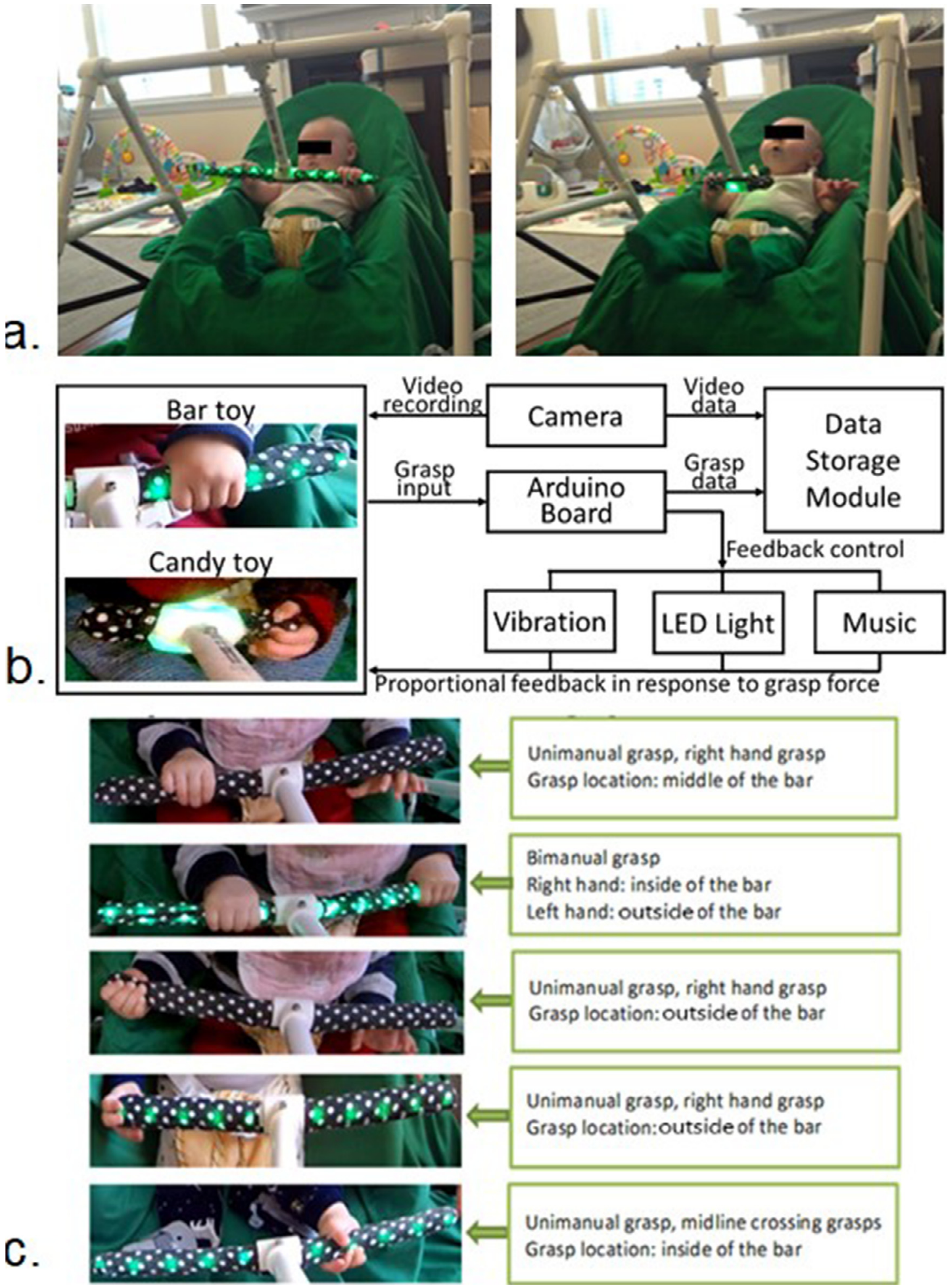

Fig 1 **(A)** Infant grasps the bar toy/candy toy and gets light feedback; **(B)** acquisition system block diagram; **(C)** annotation of grasp type and location.

showed significant increasing trends in peak grasp force, average grasp force, and bimanual grasp frequency. Infants also had significantly longer accumulated grasp time as their age increased. At the same time, a declining trend was observed in the force CV (see fig 2C). When examining changes in the grasp force trajectories of individual infants (see fig 3), we found that as infants got older (within 3- to 9-month window), they usually showed a higher grasp force together with less force variance and the beginning of grasp force plateaus. Also, most grasp events achieved their peak

Table 2 Between-participants means, SDs, and 95% CIs for all outcome measures at different ages

Variable	Toy	3 mo	4 mo	5 mo	6 mo	7 mo	8 mo	9 mo
Grasping force, mean ± SD (95% CI)								
Peak force (g)	Bar toy	633.15±154.31 (228.26-998.05)	1075.01±193.53 (617.39-1532.63)	1159.75±94.13 (942.69-1376.81)	1336.79±63.54 (1196.94-1476.64)	1294.90±179.93 (880.00-1709.81)	1260.79±148.45 (924.97-1596.60)	1303.48±173.12 (858.47-1748.49)
	Candy toy	276.76±48.50 (162.09-391.44)	390.17±95.05 (157.60-622.75)	338.41±65.78 (186.73-490.10)	420.30±38.40 (335.77-504.83)	480.47±72.50 (313.28-647.65)	565.06±72.84 (400.29-729.82)	501.40±95.48 (255.96-746.85)
Mean force (g)	Bar toy	122.12±32.06 (39.70-204.53)	181.56±31.55 (106.96-256.16)	189.28±26.96 (127.11-251.45)	285.68±39.19 (199.44-371.93)	234.59±28.89 (167.96-301.22)	264.30±25.32 (207.02-321.57)	248.75±23.72 (187.78-309.71)
	Candy toy	77.86±12.43 (48.48-107.25)	70.61±10.78 (44.24-96.98)	72.82±8.44 (53.36-92.27)	81.28±8.16 (63.33-99.23)	83.64±7.43 (66.51-100.80)	122.75±13.91 (91.29-154.21)	104.32±18.41 (56.99-151.65)
Normalized force variance	Bar toy	0.70±0.07 (0.50-0.89)	0.64±0.10 (0.39-0.89)	0.54±0.04 (0.45-0.62)	0.51±0.05 (0.41-0.61)	0.45±0.03 (0.39-0.52)	0.42±0.02 (0.37-0.47)	0.46±0.04 (0.36-0.56)
	Candy toy	0.45±0.04 (0.35-0.54)	0.40±0.02 (0.35-0.45)	0.40±0.04 (0.30-0.49)	0.31±0.02 (0.26-0.36)	0.38±0.04 (0.29-0.46)	0.40±0.03 (0.33-0.46)	0.40±0.04 (0.29-0.50)
Grasp frequency, mean ± SD (95% CI)								
Total grasps (n)	Bar toy	11.9±1.7 (7.8.15.9)	23.5±2.6 (17.3-29.7)	45.8±7.4 (28.7-62.9)	30.3±3.4 (22.9-37.6)	30.2±3.3 (22.6-37.8)	22.8±3.1 (15.7-29.9)	29.5±5.0 (16.7-42.2)
	Candy toy	8.8±1.9 (4.3-13.2)	29.3±10.8 (2.9-55.7)	19.1±2.4 (13.7-24.6)	21.6±2.9 (15.1-28.1)	15.3±3.3 (7.8-22.9)	15.9±1.7 (12.1-19.7)	15.7±4.1 (5.0-26.3)
Bimanual grasps percentage	Bar toy	0.10±0.04 (0.00-0.21)	0.12±0.04 (0.03-0.20)	0.32±0.02 (0.27-0.38)	0.29±0.03 (0.22-0.36)	0.30±0.03 (0.23-0.36)	0.26±0.05 (0.14-0.38)	0.30±0.06 (0.15-0.45)
	Candy toy	0.03±0.02 (0.02-0.09)	0.14±0.06 (0-0.29)	0.11±0.03 (0.04-0.18)	0.20±0.04 (0.11-0.29)	0.12±0.03 (0.05-0.19)	0.19±0.03 (0.12-0.27)	0.16±0.06 (0-0.33)
Grasping time-mean ± SD (95% CI)								
Minimum duration (s)	Bar toy	1.07±0.30 (0.30-1.84)	0.68±0.19 (0.22-1.13)	0.56±0.07 (0.40-0.72)	0.68 ±0.08 (0.49-0.86)	0.73±0.06 (0.59-0.86)	0.80±0.06 (0.66-0.94)	1.38±0.46 (0.21-2.55)
	Candy toy	1.45±0.60 (0.03-2.87)	0.36±0.05 (0.23-0.49)	0.59±0.09 (0.39-0.80)	0.54±0.09 (0.34-0.74)	0.70±0.12 (0.43-0.97)	0.72±0.11 (0.47-0.96)	1.20±0.45 (0.04-2.36)
Median duration (s)	Bar toy	5.33 ±0.79 (3.30-7.35)	5.28±1.94 (0.69-9.87)	2.71±0.5 (1.46-3.95)	3.42±0.45 (2.43-4.41)	4.70±1.16 (2.03-7.37)	4.21±0.54 (2.99-5.43)	4.56±0.87 (2.34-6.79)
	Candy toy	2.89±0.56 (1.57-4.20)	1.68±0.25 (1.06-2.29)	2.02±0.26 (1.42-2.63)	2.04±0.28 (1.43-2.64)	2.86±0.53 (1.63-4.09)	4.39±0.74 (2.71-6.06)	3.45±1.06 (0.73-6.17)
Accumulated grasp time (s)	Bar toy	109.58±42.67 (0.10-219.26)	147.22±37.21 (59.23-235.21)	174.47±18.02 (132.91-216.04)	213.81±19.19 (171.57-256.05)	182.49±30.71 (111.68-253.29)	180.67±32.54 (107.06-254.29)	192.94±29.18 (117.94-267.94)
	Candy toy	37.09±9.31 (15.06-59.11)	77.58±33.36 (4.04-159.19)	63.54±13.33 (32.80-94.29)	80.29±19.63 (37.09-123.48)	72.47±16.28 (34.94-110.01)	100.41±11.97 (73.33-127.49)	68.84±24.75 (5.21-132.78)
Grasp locations on the bar toy-mean ± SD (95% CI)								
Inside percentage	Bar toy	0.22 ±0.08 (0.01-0.43)	0.25 ±0.07 (0.08-0.41)	0.14 ±0.02 (0.08-0.19)	0.24 ±0.05 (0.13-0.34)	0.19 ±0.03 (0.11-0.26)	0.22 ±0.04 (0.12-0.32)	0.25 ±0.10 (0.01-0.51)
Middle percentage	Bar toy	0.70 ±0.09 (0.48-0.92)	0.52 ±0.08 (0.33-0.71)	0.58 ±0.08 (0.40-0.75)	0.53 ±0.09 (0.34-0.72)	0.67 ±0.06 (0.52-0.81)	0.56 ±0.05 (0.45-0.66)	0.53 ±0.12 (0.22-0.84)
End percentage	Bar toy	0.08 ±0.04 (0.01-0.17)	0.23 ±0.09 (0.01-0.45)	0.29 ±0.09 (0.07-0.50)	0.23 ±0.07 (0.09-0.38)	0.14 ±0.04 (0.04-0.24)	0.22 ±0.04 (0.14-0.30)	0.22 ±0.03 (0.15-0.28)
Mid cross percentage	Bar toy	0.00 ±0.00 (0.00-0.00)	0.00 ±0.00 (0.00-0.00)	0.01 ±0.01 (0.01-0.02)	0.01 ±0.00 (0.00-0.02)	0.00 ±0.00 (0.00-0.00)	0.04 ±0.02 (0.01-0.09)	0.05 ±0.04 (0.04-0.15)

Abbreviation: CI, Confidence interval.

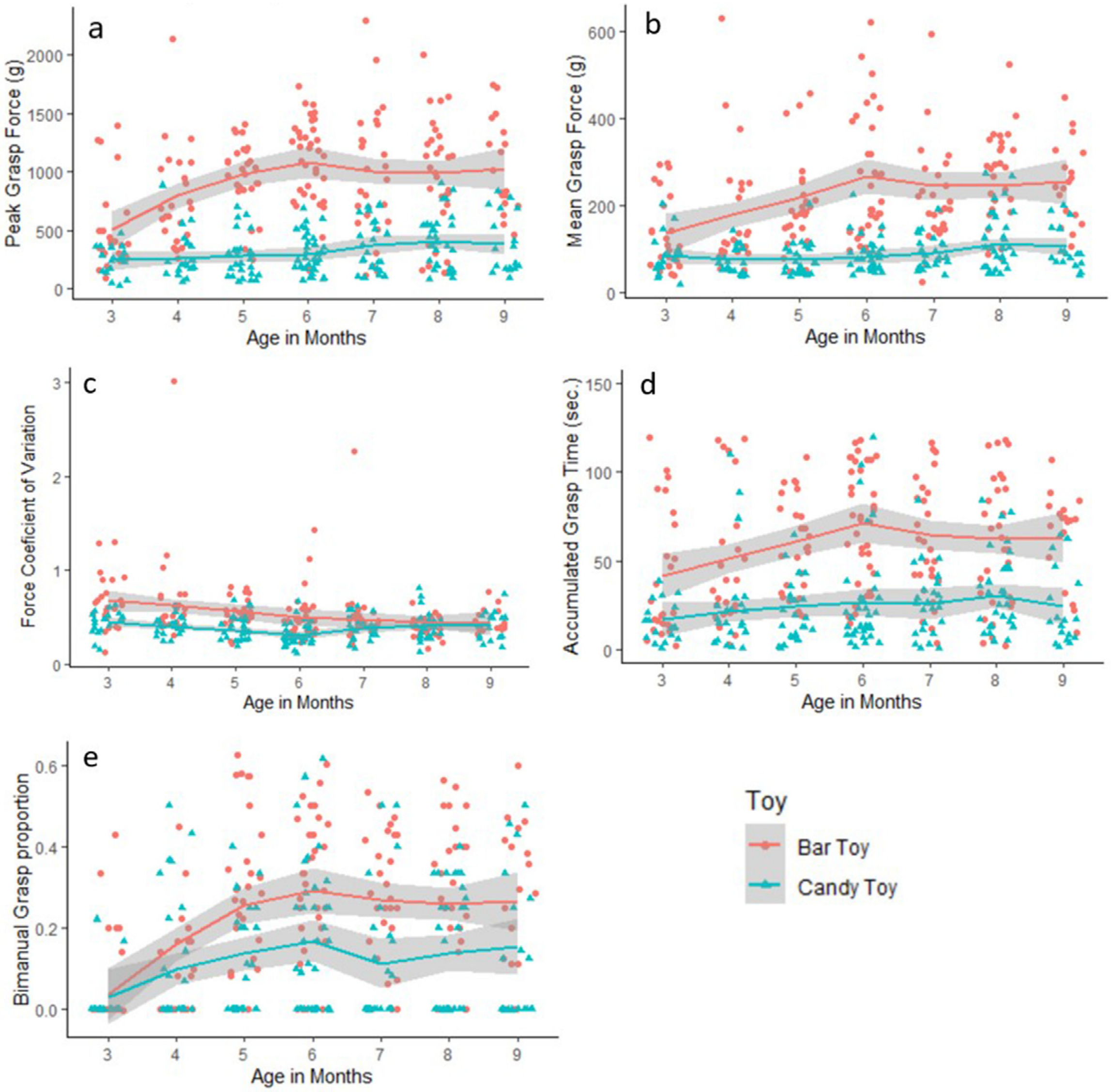

Fig 2 Main outcome measures that age and/or toy factors showed significant effects in the mixed-effects model, including subfigure (A) peak grasping force in grams; (B) mean grasping force in grams; (C) force coefficient of variation; (D) accumulated grasping time in seconds; and (E) proportion of bimanual grasps in total grasps of each session. The smoothing lines in each subfigure represent smoothed conditional means for each group using Loess method with 95% confidence intervals.

force/force plateau faster. Essentially, the force trajectories began to resemble skilled use of the hand when grasping objects. Our findings agree with a prior study that found an increase with age in the forces applied when performing both precision and power grasps.[36] Another study also reported increases in power grip force between 18 and 30 weeks of age followed by a plateau period.[24]

As infants grew older, they tended to grasp more toward the outside of the bar toy vs toward the middle portion of the bar, and they also began to develop midline crossing grasps. These trends may be indicators of increased range of controlled motion in infants' upper extremities and increased cross-hemispheric axonal connections. These age-related findings align with the stages of fine motor development.[37] The hand use and grasp sensor system also showed potential to provide quantitative assessment of hand use symmetry during the developmental process, which would be atypical in unilateral brain injury or anomalies of commissural axonal tracks.[38]

Study limitations

The sample size was small and the longitudinal follow-up process was interrupted by the COVID pandemic. A larger sample may be needed before results can be generalized. Myriad situational variables, including mental state (ie, awake, drowsy, irritable), may affect the number, duration, and strength of infant grasp events during a recorded session. For example, in the CareToy gym study, providing trunk support had been associated with earlier observation of bimanual grasping.[39] We did not collect any other demographic information (besides sex and age) for the infant participants during each home visit (eg, the height/weight z

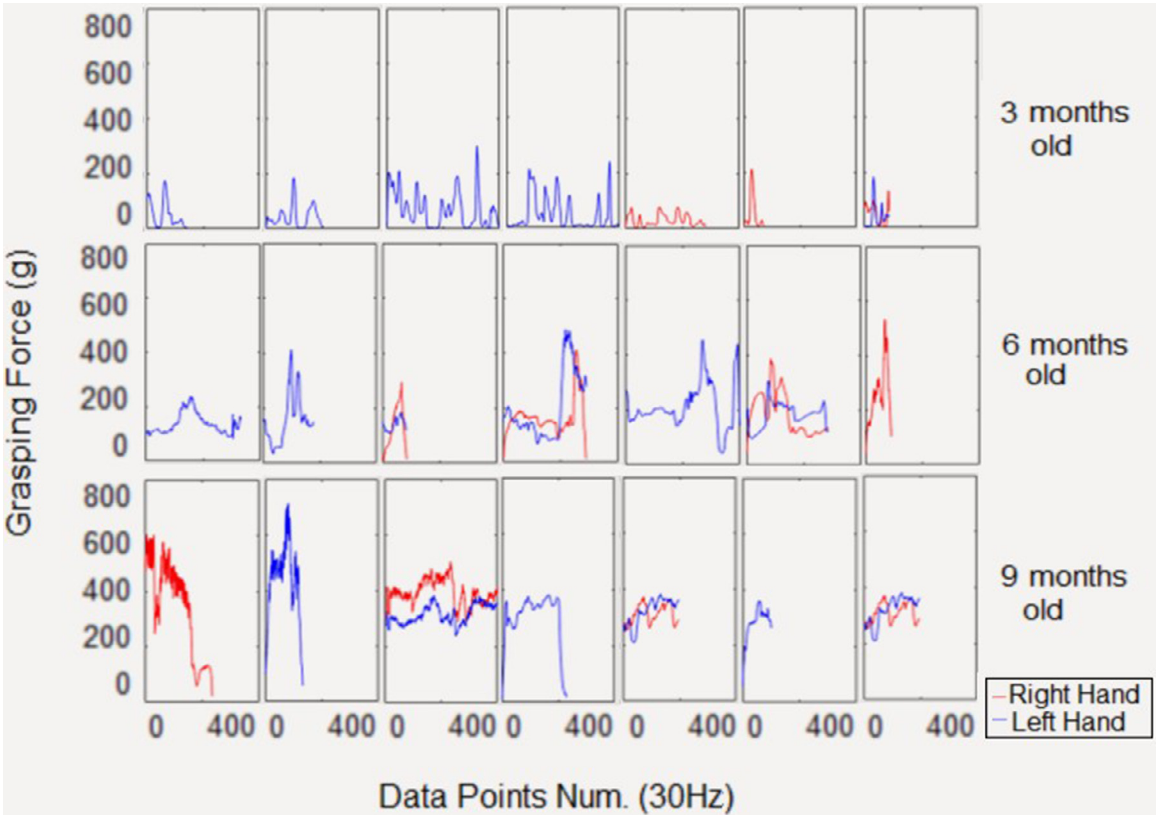

Fig 3 Example grasp trajectories at different ages. This fig displays typical grasp trajectories at 3 mo old (top), 6 mo old (middle), and 9 mo old (bottom), respectively. The y-axis of each subplot represents the grasping force in grams. The x-axis of each subplot represents the first 400 data points of each grasp at a sampling rate of 30 data points per second.

scores of the participants). There is a possibility of selection bias because caregivers had to have time to accept visitors during the day, and the socioeconomic status of participants might have been restricted because of the requirement of living within reasonable driving range from the laboratory.

Conclusions

Despite these limitations, our study demonstrated that hand use and grasp sensor has potential to quantify infant grasp development. The calculation of right hand ratios on these grasp related outcomes also showed potential to provide objective and quantitative measurements of hemispheric asymmetry. Through this research, we observed significant changes in grasp performance with age that are consistent with maturation of grasp skill, such as increasing force and grasp frequency and decreasing force fluctuations (increasing grasp stability).

Future directions of research

In future work, we will modify the protocol so that infant caregivers can collect longitudinal data on their own in their home. We also plan to test infants at risk of developmental delay and compare their grasp development with the patterns observed in typically developing infants. We envision the evolution of hand use and grasp sensor technology into an inexpensive and convenient tool to track infant grasp development with the goal of using this technology for early detection of possible developmental delay and/or cerebral palsy as a supplement to clinical evaluations.

Suppliers

a. R3 microcontroller; Arduino CC, Somerville, MA.
b. Force-sensing resistors; Interlink Electronics Inc, Irvine, CA.
c. Digital card; SanDisk Corporation, Milpitas, CA.
d. Action camera; Eken, ShenZhen, China.
e. MATLAB 2020a; MathWorks, Natick, MA.
f. SPSS version 25.0; IBM, Armonk, NY.

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