The impact of toy design on natural play interactions of premature infants

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INTRODUCTION

One in ten infants in the United States is born prematurely, with rates nearly doubling globally, and on the rise since 2015 [1]. This is of concern as these infants, especially if born with a very low birth weight, have a significant chance of having delays, such as cerebral palsy (CP) or other cognitive, motor, or developmental issues [2]. Early detection in this population can lead to earlier intervention allowing these infants to develop higher function in the future. Current methods for detection and screening disorders like CP are often qualitative, time consuming and expensive, leading 50% of clinicians to forgo these methods [3].

Sensorized toys (**Figure 1**) were created to capture reach actions and grasp forces of infants' ages 1-11 months to quantify typical and atypical development. To accomplish this, the toys needed to successfully engage infants in natural play. Eliciting engagement is a complicated relationship between stimulus, such as toy patterns and design, and affordance [4]. Understanding and quantifying this complexity would allow for better data collection in the future, but also shed light on how to best engage premature infants in play. In addition, looking at the neonatal intensive care unit (NICU) was of interest as most premature infants start there and their ability to play naturally may be restricted, which may influence toy design.

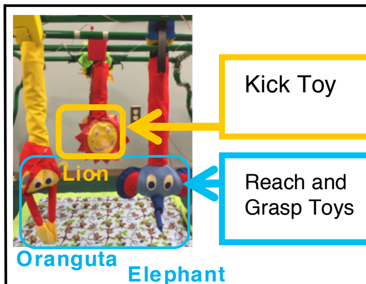

Figure 1. The three sensorized toys, the elephant and orangutan are upper limb toys, while the lion is a kicking toy

Literature shows the implementation of a sensorized toy gym for early intervention by monitoring movement, toy interaction, and pressure distribution in ecological settings. Four toys of basic shapes including a cylinder, a horseshoe, a large ring, and a small ring were designed using affordance to encourage specific grasping patterns. Light and sound feedback were also incorporated inside the toys to stimulate active play. Further tests, validated developmental differences detected by the toys [2]. These results demonstrate that sensorized toys may show promise in picking up atypical behavior in populations, such as premature infants.

Therefore, this study aims to further explore the impact of various toy designs on infant engagement. It is hypothesized that the older infants will have greater toy interactions due to increased motor development, and that there will be a distinction between toy attractions with the best overall design eliciting the most engagement.

TOY DESIGN

Of the three toys that were developed, two are upper limb toys, an elephant and orangutan, and one is a lower limb toy, a lion (**Figure 1**). All three toys are equipped with inertial measurement units (IMUs) (MPU-9150, InvenSense, San Jose, CA) to capture toy movement as well as LEDs and a soundboard (Audio FX SoundBoard, Adafruit, New York City, NY) to provide visual and auditory feedback. The first upper limb toy, the orangutan, was designed to test bimanual dexterity, allowing an infant to pry the toy's hands apart. The hands are held together via a magnet, and a reed switch would detect the unclasping of the toy's hands. The elephant has a pressure transducer (MS4525 3.3V 015 DS Type A, TE Connectivity, Switzerland) in its trunk for grasp measurements.

The toys were designed to draw an infant's attention via auditory, visual feedback and affordance. The LEDs are placed in the lion and orangutan's cheeks and the elephant's ears with each toy making a sound eponymous to its animalistic design. Additionally, if the elephant's trunk is pressed, the orangutan's arms are opened, or the lion is kicked to a certain degree, the LED lights and animal noises would activate until the action was complete. These features created a more dynamic stimulus. To make the toys intuitive, the upper limb toys' grasping sections, arms and trunk, are long and easy for the infant to reach for, while the kicking toy is wide for facile kicking.

METHODS

The toys are part of an overall Play And Neuro Development Assessment (PANDA) gym, created to address the lack of quantitative and affordable methods for screening young infants during regular play by either clinicians or parents and is additionally made up of a vision system, and a center of pressure detecting mat [3,5].

A 34 infant pilot study was run in the overall PANDA system with infants up to 11 months of age. Two groups of infants were collected, premature and full term, with a majority of the premature babies located in the neonatal intensive care unit (NICU) at the Children's Hospital of Philadelphia (CHOP). Each testing session was composed of two different conditions. In one session, the baby was allowed to play in the gym without any toys, while in another session each of the individual toys was presented. Each of the four conditions lasted for two minutes. Some infants had multiple trials within each session. Each of the sessions was recorded with the PANDA vision subsystem, consisting of four cameras, two with a bird's eye view and two with a side view.

Table 1. Demographics on infants in study

Infant Study Number	Chronological Age (months)	Corrected Age (months)	Weight (kgs)	In NICU during Testing?
30	7.9	5.2	5.66	No
31	6.5	4	6	Yes
32	5	1.5	5	Yes
33	5	1	4.12	Yes
34	6.5	5.5	8.6	Yes

To accurately assess the effectiveness of the toy designs, only test sessions where all three toys were properly presented to the infant and where there was corroborating video data were considered. Of the 34 infants, only five met the criteria; demographics can be found in **Table 1**. The remaining infants had none, one, or only two toys. Lack of toy data was often due to toy failure or camera failure. Here, because these infants are premature, we recorded both chronological age (from actual birth) and corrected age (from the nine-month due date).

While there is still some debate as to whether chronological or corrected age should be used to evaluate preterm infants developmentally, emerging literature seems to support using corrected age to assess gross and fine motor development, such as reaching and grasping [6]. The infants' corrected age was used for comparison of results.

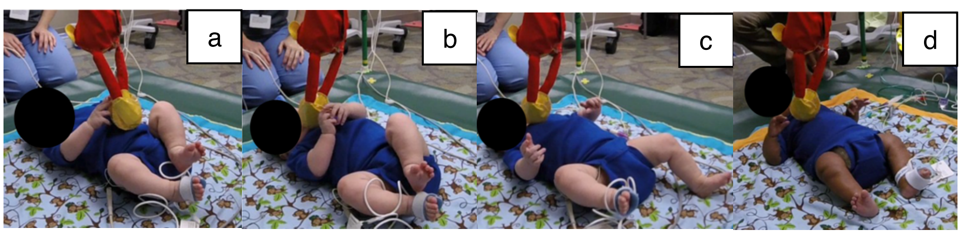

Figure 2. Examples of infant interaction: a) Voluntary interaction, the infant is touching/grasping the toy for longer than two seconds b) Involuntary limb movement interactions: the infant is accidentally moving the toy while playing with its hands c) Involuntary movements without interaction: The infant torso is accidentally moving the toy as it rests on torso d) No interaction: the baby is not moving the toy at all

To quantify engagement, the PANDA gym's video recording of the infants was used to evaluate toy interaction. Four different interactions were defined from the videos. ***1) Voluntary interactions*** **(Figure 2a)**: are a grasp/touch of toy for two seconds, where grasp/touch is visually defined as some fingers wrapping around the toy. ***2) Involuntary limb movement interactions*** **(Figure 2b)**: are involuntary grazes of toy by an infant limb, such as an infant accidentally moving the toy while playing with its own hands. ***3) Involuntary movements without interaction*** **(Figure 2c)**: are toy movements caused by infant's moving torso from the toy resting on the infant and no limbs are touching toy. ***4) No interaction*** **(Figure 2d)**: occurs when there is no toy movement due to infant. The five video sessions were carefully observed, and interaction was noted.

The total number of voluntary interactions that each infant had with each toy was calculated by dividing the time that the infant intentionally interacted with the toy by two, since each voluntary interaction was defined as a two second grasp or touch. For odd number time intervals, the number of interactions was rounded up to the nearest interaction. The x, y and z-axis acceleration collected from the IMU was also used to try and confirm interactions with toy movements. To make sure all data starts at a zero reference, the total average of each session for each axis was subtracted. The magnitude was then calculated to find overall toy acceleration.

RESULTS

Because infants develop reach/grasp at around four months, to determine whether age had an impact on toy interaction, the results were divided at the four-month mark [3]. From **Figure 3,** it can be seen that no infants (0/2) younger than four months intentionally interact with the toys, while all the infants older than four months (3/3) interact with at least two of the toys.

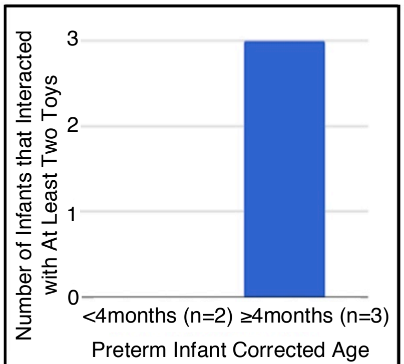

Figure 3. Interactions organized by age showing that infants <4 months do not interact with the

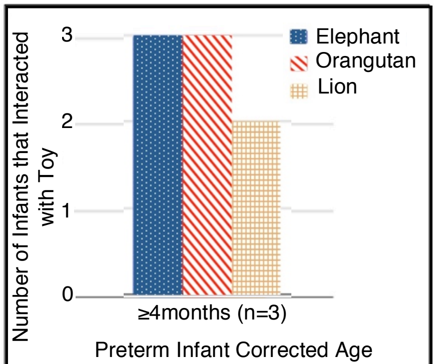

Figure 4. Interactions organized by toy showing that all but one infant had at least one interaction with all

Figure 4 shows in more detail the voluntary interactions between the toys. All the infants above four months played with the elephant and orangutan, while two of the three interacted with the lion at least once. **Table 2** shows the number of voluntary interactions each infant had with each toy. For the upper limb toys, from the infants older than four months, two intentionally interacted more with the orangutan than the elephant, while one had relatively equal number of interactions. Only one infant had numerous interactions with the lion.

Table 2. Voluntary Infant Interactions for Upper Limb Toys

Infant Study Number	Corrected Age (months)	Number of Interactions with Elephant	Number of Interactions with Orangutan	Number of Interactions with Lion
30	5.2	25	96	0
31	4	9	34	14
32	1.5	0	0	0
33	1	0	0	0
34	5.5	8	7	1

Figure 5 shows a sample overlapping of interaction and acceleration data. Here, acceleration correlated to toy movement with large acceleration spikes indicating large toy movements. **Figure 5a** is data for infant 31, older than four months, and shows toy movement during voluntary and involuntary limb movement interactions as well as during involuntary movements without interactions. **Figure 5b** is data for infant 32, younger than four months, and shows relatively no toy movement and no voluntary interaction. Since the lion toy had faulty data, kicking interactions could not be confirmed.

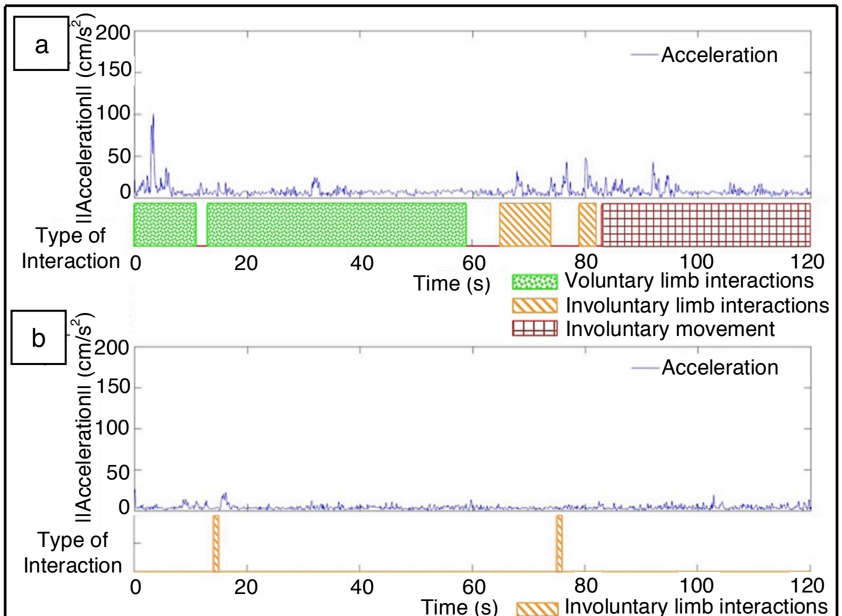

Figure 5. Infant 31 (a) and 32 (b) sample interactions overlapped with acceleration from orangutan toy IMU. a) Movement can be seen whether interaction be voluntary or not. b) The toy was not significantly accelerated by Infant 32 (less than four months).

DISCUSSION

Results show that the premature infants below four months of age did not grasp/reach for a toy, aligning with our hypothesis and with developmental milestones, as infants below this age are less likely to perform these actions. It seems that design is unable to elicit the same type of reach/grasp engagement in infants across the motor developmental age of four months. Moving forward, a new engagement and interaction design elicitation will need to be developed to cater to infants younger than four months. Focusing on gaze and subtle limb movements, like head and hand to mouth movements or opening and shutting hands will help capture younger infant interactions. The toy design should allow for voluntary engagement regardless of motor skill or age.

For the infants older than four months, both the elephant and orangutan engaged the infants, with all three voluntarily interacting with them at least once, while the lion engaged majority of infants. **Table 2** shows that the amount of voluntary interactions differed greatly between the two upper limb toys especially with infants 30 and 31. Both infants have many more voluntary interactions with the orangutan, a disparity that may be accounted by the toy's longer limbs, requiring less effort by an infant to reach. While voluntary interactions are coveted, the toy design should require effort from the infant for interaction. Otherwise, no useful measurements about reach or grasp could be garnered for developmental assessment. The elephant's trunk was higher than the orangutan's arms, requiring greater efforts to reach toward for voluntary interactions, which allows assessment of an infant's ability to reach. It therefore seems that the elephant was a more successful toy design, as it allows for quality reach/grasp measurements while still eliciting engagement. However, the orangutan's greater affordance should not be ignored and future designs should try to blend the best characteristics of the two toys.

The acceleration data showed that it alone could not distinguish between the types of interaction of the infant. The toy movement was seen whether there was a voluntary or involuntary interaction in infant 31. However, it was able to grossly distinguish between ages. If all infants follow the trend of this study, and those that are younger than four months do not interact with the toy, acceleration data may be a way to discriminate between infants greater and younger than four months. Nevertheless, to fully quantify the types of interaction, different sensors will need to be explored or automated video may need to be incorporated [5].

A limitation of this study is the low sample number; patterns that are seen in this study may not apply to larger premature infant or typically developing groups. Additionally, there is inherent human error involved when manually analyzing videos. User bias is present as observations are subjective. Unfortunately, there is not much that can be done to mitigate this as looking at videos will always introduce a certain amount of subjectivity. There was also some interference from parents and overseers during the sessions. Infants 32 and 33 had someone holding a pacifier in their mouths, partially blocking the infants' field of vision. This may have impacted toy interactions by preventing a full view of the toy. Such interferences will need to be accounted for in future analysis.

Any future design changes to the current toys will need to be made taking this study's findings into consideration. One such change that will occur is in the electronic robustness of the toys. As stated previously, not all the toys could be presented properly to all the infants, which was due to some electronic mechanisms within the toy failing. Adding a 3D printed shell around the electronics may offer some protection from the use leading to fewer failures. Lastly, future iterations will focus on decreasing the complexity of the system by reducing the number of toys from three to one, where the best characteristics of the current three toys are incorporated into one toy.

CONCLUSIONS

Voluntary toy interaction in premature infants is dependent on age and design, and to allow for proper collection of reach and grasp measurements for developmental assessment, there needs to be an equal exchange between affordance and effort. Acceleration is also not enough to quantify voluntary interactions and new sensors need to be explored to capture this parameter.

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