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An INNOVATIVE USE of TECHNOLOGY and ASSOCIATIVE LEARNING to ASSESS PRONE MOTOR LEARNING and DESIGN INTERVENTIONS to ENHANCE MOTOR DEVELOPMENT in INFANTS

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A dissertation submitted in partial fulfillment of the requirements for the Doctor of Philosophy in Rehabilitation and Movement Science at Virginia Commonwealth University.

by

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Abstract

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Since the introduction of the American Academy of Pediatrics Back to Sleep Campaign infants have not met the recommendation to "incorporate supervised, awake "prone play" in their infant's daily routine to support motor development and minimize the risk of plagiocephaly". Interventions are needed to increase infants' tolerance for prone position and prone playtime to reduce the risk of plagiocephaly and motor delays. Associative learning is the ability to understand causal relationship between events. Operant conditioning is a form of associative learning that occurs by associating a behavior with positive or negative consequences. Operant conditions has been utilized to encourage behaviors such as kicking, reaching and sucking in

infants by associating these behaviors with positive reinforcement. This dissertation is a compilation of three papers that each represent a study used to investigate a potential play based interventions to encourage prone motor skills in infants. The first paper describes a series of experiment used to develop the Prone Play Activity Center (PPAC) and experimental protocols used in the other studies. The purpose of the second study was to determine the feasibility of a clinical trial comparing usual care (low tech) to a high-tech intervention based on the principles of operant conditioning to increase tolerance for prone and improve prone motor skills. Ten infants participated in the study where parents of infants in the high tech intervention group (n=5) used the PPAC for 3 weeks to practice prone play. Findings from this study suggested the proposed intervention is feasible with some modifications for a future large-scale clinical trial. The purpose of the third study evaluated the ability of 3-6 months old infants to demonstrate AL in prone and remember the association learned a day later. Findings from this study suggested that a majority of infants demonstrated AL in prone with poor retention of the association, 24 hours later. Taken together these 3 papers provide preliminary evidence that a clinical trial of an intervention is feasible and that associative learning could be used to reinforce specific prone motor behaviors in the majority of infants.

Chapter 1: Introduction

The “Back to Sleep, Prone to Play” campaign by the American Academy of Pediatrics is a public health intervention, specifically aimed at encouraging parents to 1) place their infant(s) in supine position for sleep to prevent Sudden Infant Death Syndrome (SIDS) and 2) practice supervised, awake prone play, every day to support their infant’s development and minimize the risk of positional plagiocephaly. The “Back to Sleep” arm of this campaign has been successful in reducing the incidence of SIDS from 130.3 deaths per 100,000 live births in 1990 to 39.4 deaths per 100,000 live births in 2015.(Jantz, Blosser & Fruechting, 2011) Similar success is not seen in response to the campaign’s “Prone to play” recommendations. Approximately 70 % of 4-5 months old infants are spending more time in supine position, supported sitting or being held (mean (M) = 8.9, standard deviation (SD) = 1.26) compared to prone position (M = 1.2, SD = 1.1) during a 10 hour awake period.(Dudek-Shriber & Zelazny, 2007) Lack of prone play in an infant’s routine can be associated with several factors ranging from parent’s awareness and attitude towards AAP’s “Prone to play” recommendations to the challenges they face while implementing it. The purpose of this perspective paper was to: 1) discuss the importance of prone play in an infant’s routine 2) why prone play is a challenging activity and 3) efficacy of existing strategies that are in use to improve prone play in an infant’s routine and 4) propose a conceptual model describing the use of associative learning and motor learning strategies to improve the implementation of prone play to guide future research.

Importance of Prone Play

The “Back to Sleep” (BTS) campaign was initiated in 1992 to encourage safe sleep practices during infancy and reduce the incidence of Sudden Infant Death Syndrome (SIDS). SIDS is sudden, unexplained death usually during sleep of a seemingly healthy infant less than 1 year of age.(Luca & Hinde, 2016) Sleeping in a prone position has been identified as one of the main factors contributing to SIDS and parents are advised to not to put their infant to sleep in prone position.(Galland, Taylor, & Bolton, 2002) The “Back to Sleep” campaign was successful in reducing the incidence of SIDS but it caused an unanticipated change in infants’ play routine.(Bronfin, 2001; Jones, 2004) A significant decrease in time spent in prone position in comparison to other play positions has been documented in 0-6 month old infants.(Jones, 2004; Kuo, Liao, Chen, Hsieh, & Hwang, 2008; Leung, Mandrusiak, Watter, Gavranich, & Johnston, 2017; Russell, Therapy, Kriel, & Physiotherapy, 2009; Zachry & Kitzmann, 2011) This shift in play routine of infants led to numerous reports of poor performance in motor developmental measures seen in infants with no prior history or risk factors for developmental delays. In addition to the reports of developmental delays, an increase in the incidence of three musculoskeletal conditions, plagiocephaly, torticollis and shoulder retraction was seen following the “Back to sleep” campaign.(Jones, 2004) In the following subsections, the impact the “Back to sleep” campaign had on infants’ gross motor development and musculoskeletal system is discussed in detail.

Prone play and motor development. A retrospective analysis of 343 typically developing infants’ published in 1997 described the primary sleep position and scores on a motor development measure administered at their 4 or 6 months of age follow up checkup.(Davis, Moon, Sachs, & Ottolini, 1998) The Denver Development Screening Test- Revised (DDST-R) was used to screen infants to quantify the extent of their motor development. Findings from this report suggested that infants who slept in supine or side lying position had a delay in rolling over at 4 months of age.

Tarabulsy and colleageus used parent reports to determine infants' primary sleep position at 1 month of age and administered a questionnaire based on the DDST-R to evaluate infants' developmental status at 6 and 18 months of age. Findings from this study suggest that infants who slept predominantly on their backs were not performing optimally in certain gross-fine motor skills such as transferring small objects between hands and social domains of development at 6 months of age.(Hunt, Fleming, Golding, & the ALSPAC Study Team, 1997) However, no statistically significant developmental disadvantages for supine sleepers were seen at 18 months of age.

Both the research reports weighed their findings against the adverse effects of putting infants to sleep in prone position, and the risk of SIDS associated with prone sleeping was suggested to be a much higher risk than the risk of developmental delay. Thus, none of these reports proposed a change in the AAP's "Back to Sleep" recommendations existed in their time. Even though the initial reports of developmental delays observed after the "Back to sleep" campaign were inconclusive they did raise questions and concerns on 1) what mechanism led to the un-anticipated sequelae observed in development of infants born during and after the "Back to Sleep campaign" and 2) long term consequences imposed by delays in gross motor development, even though transient in nature, on infant's exploration during the critical periods of learning present early in development.

To address these concerns Salls, Silverman and Gatty (2002) asked 66 parents of 2 ,4 and 6 months old infants to document their infant's 1) sleep position (supine, side lying or prone) and 2) duration of each play position their infant spends in during the wakeful period of the day.

They found that a majority of parents who are practicing AAP's safe sleep recommendations i.e putting their infants to sleep in supine position are avoiding prone position even during the day. A comparison of the gross motor development of infants who spent less than 15 minutes and those who spent greater than 15 minutes of awake prone time.(Salls, Silverman, & Gatty, 2000) showed that those infants spent more than 15 minutes of awake prone time had better performance in certain motor milestones (holding head steady – 45° and 90° in prone and sitting) compared to infants who spent 15 minutes or fewer of awake prone time.

In 2008, American Physical Therapy Association (APTA) carried out a national survey of 400 pediatric physical and occupational therapist, where two thirds of the PTs and OTs reported motor delays seen in infants who spend too much time on their backs while awake.(Newswire, York, & York, 2008) This survey suggested that infants' poor tolerance for prone and uncertainty of parents on how to practice tummy time were prime contributors of limited tummy time in an infant's routine placing them at the risk of motor delays.

While healthy typically developing infants are at risk of mild developmental delays and plagiocephaly due to limited prone play, a larger impact is seen on infants with a pre-existing risk of developmental delays, like infants born at preterm.(Fetters, Huang, 2007) Barlett & Fanning determined if a relationship exists between infants least "favorite" play position, duration of equipment use and motor development in 8 months old infants born at preterm. Their findings suggests that due to prone being the least "favorite" position infants spend less amount of time in prone and perform poorly in motor skills in prone compared to other play positions. In addition, excessive use of a swing where the infant is positioned predominantly in supine was related to poor performance in prone motor skills.(Bartlett & Fanning, 2003) Infants born preterm have a different development trajectory than infants born at term.(Butler & Als, 2008) In addition to reports of poor prone play routine of preterm infants at home, around 65% and 33% of preterm infants prefer to position their head to one side at term equivalent age and 6 months of AA, respectively.(Nuysink et al., 2013) Prolonged stay in the NICU, history of mechanical ventilation, and multiple births are identified as factors that may contribute towards positional preference commonly seen in preterm infants.(Nuysink et al., 2013) Positional preference can cause an asymmetry in the strength of the neck musculature and have an impact on infants' ability to raise their head in prone. This can further add on to the biomechanical challenges imposed by prone position on infants.

When I put the above findings together it presents a model explaining the mechanism that may have driven the relationship between infants who sleep on their back and their poor performance in developmental measures. This relation is under the influence of parents avoiding prone play in their infant's routine either due to fear of SIDS or lack of awareness of the importance of prone play and infant's intolerance towards prone play (Figure 1).

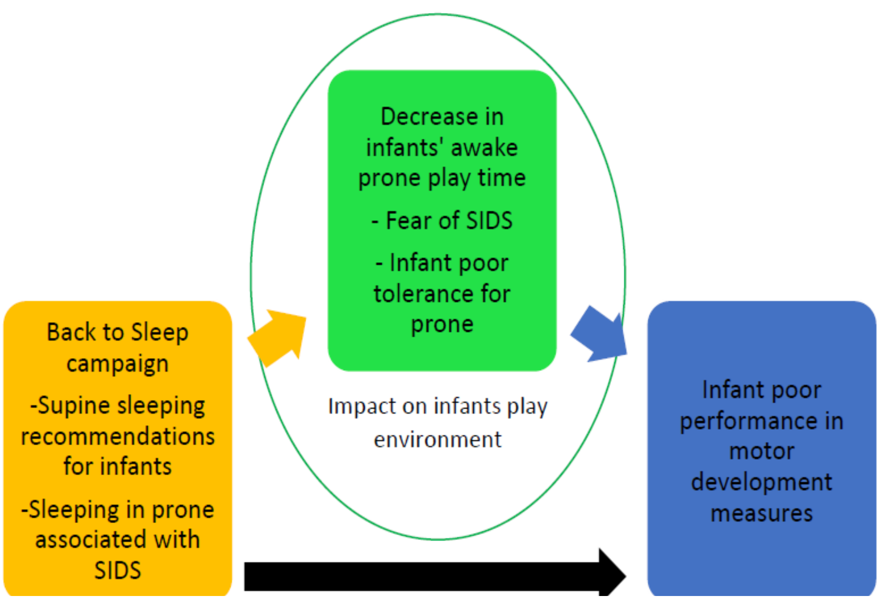

Figure 1. Mechanism of change in play routine of infants due to Back to Sleep recommendations

Theoretical justification of the change in prone play routine impacting prone motor skills model. The Dynamic system theory (DST) provides an inclusive perspective to why lack of prone play in infants' routine impacts their gross motor development. According to this theory, infant motor development is a product of interactions between multiple intrinsic (central nervous system and musculoskeletal system) and extrinsic (environment, demands of task) elements.(Thelen, 1995a) Environment plays a crucial role in an infant's development as it provides motor and cognitive opportunities such as the position in which the infant is placed and the toys available for exploration and interaction.(Lobo, Harbourne, Dusing, & Mccoy, 2013) For example, infants learn to kick their feet and bring their feet to their hands while supine through practice and accidental success, which strengthens abdominal and hip flexor muscles, and gradually transitions to goal oriented movements. The "Back to sleep" campaign has an unanticipated effect on the play environment of infants. Fear of SIDS discourages parents and caregivers from placing from positioning their infant in prone even during waking hours.(Salls et al., 2000) Limited prone play practice results in young infants not having a play position in which they can visualize the world in front of them, practice early weight shifting to free an arm for reaching, and limits opportunities to learn prone mobility such as commando crawling through their spontaneous leg movements. Consistent with the DST, the lack of these early experiences could contribute to delays in visual perceptual skills, understanding of cause and effect, and reduced experience of independent discovery or practice leading to acquisition of a novel motor skill in prone. The potential impact of lack of prone play on infants' ability to learn a task in prone has not been tested.

Musculoskeletal implications of reduced prone play.

Positional plagiocephaly and positional torticollis. Since the implementation of the "Back to Sleep" campaign in 1992, a rise in the incidence of PP and PTC has been observed. During infancy the cranial bones are membranous and thin in density, joined by sutures that gets ossified at 20-24 months of age.(Bronfin, 2001) The space between the cranial bones known as fontanelles allows the cranial bones to overlap and pass through the birth canal. The fontanelles accommodates for the changes in skull shape that happens due to the rapid growth of the brain during infancy.(Williams, 2008) Since, infant's cranial bones are soft and not ossified if the first months of life their shape is highly adaptable and can undergo deformation in response to the application of an external force/pressure. Positional plagiocephaly (PP) (also known as deformational plagiocephaly) refers to an acquired flattening of one side of the parieto-occipital region of the skull causing a compensatory anterior shift of the ipsilateral ear and bulging of the ipsilateral forehead in infants.(Klimo et al., 2016b; Linz, Kunz, Boehm, & Schweitzer, 2017) In 2013, an estimated 20 % of the almost 4 million infants born in the United States experienced some degree of positional deformation of the skull.(Klimo et al., 2016a) Positional torticollis (PTC) is a musculoskeletal condition commonly seen in infants with PP.(Martiniuk, Vujovich-Dunn, Park, Yu, & Lucas, 2017) PTC is described as tightening of the sternocleidomastoid muscle resulting in lateral flexion of infant's neck to the affected side and rotation to the opposite side. PTC can occur alone or in association with PP. However, a higher incidence is seen in infants with PP then in the general population.(Losee, Mason, Dudas, Hua, & Mooney, 2007) Around 50 % and 37% of preterm infants are identified to have PP at 3 and 6 months of adjusted age, respectively. Linz et al, 2017 in their review on etiological factors leading to PP, identified limited intrauterine space due to multiple births, restricted cervical spine mobility due to congenital torticollis, prematurity, developmental delays, excessive supine lying, limited prone play time, positional torticollis, and preference to hold the head to one side as the risk factors associated with PP.

Clinicians considered PP as just a cosmetic condition seen in pediatric population. In the last decade, evidence of infants with PP experiencing subtle developmental delays has increased.(B. Collett, Breiger, King, Cunningham, & Speltz, 2005; Kennedy, Majnemer, Farmer, Barr, & Platt, 2009) In 1992-1999, right after the "Back to Sleep" campaign began in the United States, a drastic six-fold increase was seen in the referral rate of PP to craniofacial specialists, pediatric plastic surgeons and neurosurgeons.(Argenta, David, Wilson, & Bell, 1996; Kane, Mitchell, Craven, & Marsh, 1996; Turk, McCarthy, Thorne, & Wisoff, 1996)

Martiniuk et al, 2017 in their systematic review evaluated the association between plagiocephaly and developmental outcomes in 0-24 months old infants.(Martiniuk et al., 2017) Nine out of 11 studies indicated an association between PP and developmental delays in 7-8 months old infants. Infants with PP had low scores in the motor domain of the Bayley Scale of Infant Development (BSID)(B. R. Collett et al., 2013; Brent R. Collett et al., 2011, 2012; Speltz et al., 2010) and were identified to have low and variable muscle tone in the Hammersmith Infant Neurological Examination (HINE) compared to their same age group peers without PP.(Fowler et al., 2008) In addition to the neurodevelopment screening tools (BSID and HINE), structural measures such as brain asymmetry evaluated using MRI was positively correlated with plagiocephaly.(Brent R. Collett et al., 2012) An intersection between findings of brain asymmetry identified in MRI and motor development delay diagnosed using BSID-3rd edition was seen in 7.9 months old infants with plagiocephaly.(Brent R. Collett et al., 2012) To summarize, evidence suggests that there exists a relation between PP and developmental delays, however Collet et al, in their studies specified that there is not a casual relation between PP and developmental delays. PP is suggested to be a “marker” indicating factors such as underlying brain pathology, prematurity, an over use of positioning devices, limited prone play time and excessive supine lying that can cause a delay in the development of infants.(B. Collett et al., 2005)

In addition, PP can be stressful for some parents as they are worried about their infant’s appearance and any impact PP may have on their infant’s development.[23-25,37,38] In today’s era of quick and easy access to information, parents and caregivers are inclined to use the internet sites to seek information on issues concerning their infant’s development.(Kaplan, Coulter, & Fetters, 2013) Although parents may find the vast variety of resources present in the internet about PP and PTC of use, it can be overwhelming for them to comprehend these resources.(Ohman, Nilsson, Lagerkvist, & Beckung, 2009) As will be discussed in the “current prone play practices and barrier” section, there are no clear guidelines for how much prone play is needed or how to conduct it.

Shoulder retraction. Infants who spend a majority of their time in supine have a tendency to position their shoulders in external rotation, scapular retraction and scapular abduction when placed in prone position.(Hunter & Malloy, 2002; Jones, 2004) This atypical posture is referred to as “W” position of the arms when the infant is in prone position. Georgieff & Bembaum[45] demonstrated that 46 % of infants born at preterm were identified to exhibit shoulder retraction at the NICU follow up visits during the first year of life.(Georgieff & Bernbaum, 1986) Shoulder retraction in preterm infants have been attributed to tone abnormalities that exacerbates if supine is the position an infant prefers to be in. Infants feel “stuck” in the “W” position of the arms as it can 1) affect hand-to-mouth exploration, often used for self-calming by infants 2) cause excessive arching of the neck and trunk and 3) makes forearm propping in prone a challenging activity and reducing functional play and visual explorations.(Georgieff & Bernbaum, 1986; J. C Heathcock, Lobo, & Galloway, 2008; Hunter & Malloy, 2002; Monfort & Case-Smith, 1997; Vaivre-Douret, Ennouri, Jrad, Garrec, & Papiernik, 2004)

Back to Sleep, Prone to Play Campaign

As the importance of prone play on infant development and head shape was recognized, American Academy of Pediatrics (AAP) in 2002 extended the “Back to sleep” campaign to “Back to Sleep, Prone to Play” educational campaign.(Zachry & Kitzmann, 2011) With this campaign AAP encouraged parents and caregivers to not only follow safe sleep practices but also incorporate supervised, awake “prone play” time in their infant’s daily routine to facilitate development and minimize the occurrence of positional head deformities and other associated musculoskeletal conditions in infants”.(Chizawsky & Scott-Findlay, 2005)

Factors contributing to lack of prone play in infants’ routine: current practices and barriers. The current practice to encourage prone play in an infant’s routine focuses on educating parents about the AAP’s recommendations and use of positional supports such as u-shaped pillow to make prone play less of a challenge. The “Back to Sleep and Tummy to Play” campaign encourages parents and caregivers to include prone play in their infant’s routine, 2 to 3 times a day for short periods (3-5 minutes) starting in the first days of life.(“Tummy Time - AAP.org,” 2018) AAP recommends parents progress gradually by increasing the duration and frequency of prone play as their infant shows interest and enjoys prone play. For infants who do not like prone play, parents are encouraged to position themselves or place a toy in view of the infant or place the infant on the parents chest as this position may encourage the infant to raise his/her head and use the arms to push up to see the parents face.(“Back To Sleep, Tummy To Play,” 2008)

The “Back to Sleep and Prone to Play” campaign has been successful in increasing parents” awareness towards the importance of prone play in infants’ routine. The majority (~75%) of parents have reported awareness of prone play recommendations and the complications of development delays and plagiocephaly that may occur due to limited prone play time. Yet, most parents report 15 minutes or less of prone play time per day in their infants routine.(Koren, Reece, Kahn-D’angelo, & Medeiros, 2010a; Zachry & Kitzmann, 2011) The barriers identified in the literature that may contribute towards lack of prone play can be grouped under 2 categories: 1) Infant- parent related barrier and 2) health care provider related barrier.

1) Infant - parent related barriers. Around 53 % of parents have reported that their infant does not tolerate prone position and they are able to incorporate < 10 minutes of prone play in a day.[50] Infants are born with weak neck and trunk muscles and their body is top-heavy due to large heads, which displaces their center of gravity near the center of the sternum. This creates a biomechanical challenge for infants when they lift their upper body in prone to look around and explore. For infants with large heads, weak muscles, or limited practice, prone is an unpleasant position for play.(Hunter & Malloy, 2002) Due to infants’ intolerance for prone position, some parents find it challenging to incorporate prone play in their infant’s daily routine.(Dudek-Shriber & Zelazny, 2007) A short term solution to this problem is parents may decide to move infants out of prone play to a position that is not challenging such as supine or put them on a swing/seat. In the long term, parents may perceive practicing prone play with their infant as a burden and completely discontinue the practice of prone play in their infants’ routine.(J. Guidetti, Wells, Worsdall, & Metz, 2017) This corresponds to Pin, Eldridge &

Galea (Pin, Eldridge, & Galea, 2007) findings where parents have reported their infant spending ~ 75% of the wakeful period of the day either being held or in an equipment such as a seating device that may limit learning opportunities. Thus, though prone play is important, infants' intolerance towards it makes it a challenging activity for infants to practice and for parents to implement.

Parents are looking for ways to increased tummy time with 48 percent of parents reporting the use of commercially available prone positional supports including u-shaped pillows, towel rolls, and play gyms to encourage tummy time.(Jantz, Blosser & Fruechting 2011), In a recent study, infants using u-shaped pillows were found to be more tolerant to prone in comparison to infants lying on a flat blanket.(J. Guidetti et al., 2017) This finding suggests that that equipment such as Boppy pillows are making prone play less challenging for infants as they provide additional support and reduces the efforts required from infants to raise their head. None of these toys reinforce infants self-directed movements to lift higher and raise their head and upper body for a longer period of time in prone. Abbott & Barlett(Abbott & Bartlett, 2001; Bartlett & Fanning, 2003) suggested that even though infants are in a positive state using positional supports, they are not actively working on developing their prone motor skills. Research has demonstrated that families using equipment that do not provide any reinforcement makes the infant passive and results in poor performance in measures assessing motor development.(Abbott & Bartlett, 2001; Bartlett & Fanning, 2003) Without positive reinforcement during prone play, infants may disengage, fuss or roll into supine, as there is no motivation to lift their heads higher and stay in prone. Current education programs and "tummy time toys" do not address the need for easily implemented prone play strategies that can be implemented by parents or daycare teachers.

2) Healthcare provider related barriers. A Koren, Reece, Kahn-D'angelo, & Medeiros, 2010(Koren, Reece, Kahn-D'angelo, & Medeiros, 2010b) studied healthcare providers (physician, nurses and focus groups) awareness and attitude towards prone play recommendations and its inclusion in their practices. Their findings suggests that there exist a wide variability in information related to prone play provided by the healthcare providers. The amount of prone play time the providers in their study recommended to parents ranged from 2 to 15 minutes per day with a frequency of "few times per day".(Koren et al., 2010a) Such recommendations lack clarity and may confuse parents while they are working on developing a prone play routine for their infant. At the well-child visits, information on preventing SIDS was covered at every visit but this was not the case with educating parents on implementing prone play. The age at which prone play guidelines were discussed the first time ranged from 2 - 6 months. A lack of formal prone play educational protocol for practices across the nation adds on to the inconsistency seen in the knowledge about prone play among healthcare providers. With the internet being an easy to access source of information for the general population, around 75 % of mothers use social media for parenting related information.(Duggan, Lenhart, Lampe, & Ellison, 2015) The content covered on prone play on the parenting web sites is inconsistent and misses out on information on minimum prone play time (>30 minutes/day) required to gain developmental benefits.(Koren et al., 2010b; Zachry & Kitzmann, 2011b)

Current approaches to encourage prone play i.e educational programs and use of prone positional supports lack scientific rigor. Their focus is on supporting the infant's trunk in prone to make prone play less challenging for infants. These positional supports do not positively reinforce the infant's attempts to lift their head higher or for a longer period. While commercial play gyms may have toys on the positional supports, the toy's activity is not related to infant's movement. Likewise, the toys are often accessible with the head down in prone or in supine or sitting as well. Without positive reinforcement during prone play, infants may disengage, fuss or roll into supine. An evidence based intervention approach is needed to address this significant gap in supporting the development of typically developing infants and those at the highest risk of disabilities.

Learning in Infancy

During the first year of life, substantial changes are seen in the motor and cognitive skills of human infants.(Thelen, 1995) Although the various motor and cognitive developmental milestones during infancy are well described in the literature, our understanding of the learning mechanisms underpinning their emergence is still evolving. A contemporary view of development focuses on understanding how a child is learning a developmental skill and disagrees with the traditional view of motor/cognitive skills being "hard wired" responses to growth and maturation. One purpose of this section is to briefly review the two most accepted theories of child development: Dynamic Systems Theory (DST) and the Ecological Systems Theory (EST). The second purpose is to discuss my perspective on translating the knowledge I have gained from these theoretical frameworks in designing research paradigms, assessments and interventions to quantify and improve development in infants with or at risks of motor delays. Third purpose is to discuss how technology can be utilized to achieve the second purpose. Last present the application of a learning based assessment and intervention model to enhance prone motor development and boost tolerance for prone play during infancy.

Learning based theories of motor development. Learning based theories of motor development are a group of abstract ideas about the nature and acquisition of motor skills in infants. According to DST and EST, interaction of multiple sub systems within the infant, task, and environment provide a context for infants to learn motor skills.(Thelen, 1995) Infants are considered as active learners who, through exploration, are constantly engaging with the environment.(Adolph & S. Kretch, 2015) Since movement is the ultimate function of motor development, DST and EST view motor development under the construct of movement. Human movements are organized as actions that have a purpose and are guided by the knowledge or perception of the movement itself and the environment. For instance, Kurjak et al(Kurjak et al., 2005) studied motor behaviors from fetal to neonatal period and found that the frequency of hand to mouth and hand to face exploration is higher in fetuses >27 weeks of gestation compared to neonates. This finding emphasizes the role played by the environment where the ability to move the hand to mouth/face was afforded in the intrauterine environment due to no constraint of gravity but was limited after birth.

Motor learning is described in the literature as *"set of processes associated with practice or experience leading to relatively permanent change in the capability for producing skilled actions".*(Shumway-Cook & Woollacott, 2007) Elsner and Hommel proposed a two-stage model explaining the mechanism of acquisition of motor skills in infants. Stage 1 is described as the perception stage where infants through their exploration perceive properties of the environment and their body and Stage 2 involves the selection of the most appropriate movement strategy by associating the information gained in Stage 1 to a movement plan. For example, infants spend hours and hours moving their legs spontaneously. But when presented with an overhead mobile that moves in response to their kick, infants learn to discover this association and transition from Stage 1 to Stage 2 of the motor skill acquisition model. Such learning is referred as perceptual learning, discovery learning or associative learning in the literature. On this premise I have turned my focus on associative learning which is a widely studied learning mechanism in developmental psychology. The field of developmental psychology proposes that the construct of "associative learning" is one of the basic learning mechanisms required to develop complex cognitive abilities across development.(Angulo-barroso et al., 2016; Grossberg, 1980; Jill C Heathcock, Bhat, Lobo, & Galloway, 2004a; Jongbloed-pereboom, Janssen, Steenbergen, & Sanden, 2012; Reeb-sutherland, Levitt, & Fox, 2012; Street, Washington, Hagen, & Ph, 2008)

Associative learning. Associative learning can be described as the ability to discover a relationship between two or more events.(Dickinson, 2001) It is further characterized into two behavioral learning principles: 1) Classical conditioning and 2) Operant conditioning.(*Learning and memory : a comprehensive reference*, 2008) Classical conditioning as described by Pavlov is "*a learning process that occurs when two stimuli are repeatedly paired; a response that is only elicited by the second stimulus is eventually elicited by the first stimulus alone"*. (Fitzgerald & Brackbill, 1976) A paradigm used commonly to assess classical conditioning in infants is the eye blink conditioning (EBC) paradigm. In this paradigm the stimulus that elicits closure of eyes is a gentle puff of air in the eye (unconditioned stimulus); this stimulus is paired and presented repeatedly after a visual (light) or auditory (tone) event (conditioned stimulus) for associating the conditioned stimulus with the closure of eyes elicited by the unconditioned stimulus. The learned conditioned response is closure of the eyes when exposed to the conditioned stimulus (visual or auditory stimulus), without the presentation of the unconditioned stimulus.(Reeb-sutherland et al., 2012) The second associative learning principle, Operant conditioning is described as *"a behavior that can be encouraged or suppressed by associating the behavior with a positive or negative reinforcement respectively".*(Gerhardstein, Kraebel, & Tse, 2006; C. Rovee-Collier, 1987; Tarabulsy, Tessier, & Kappas, 1996) A paradigm commonly used to assess associative learning in infants is the Rovee- Collier mobile (RCM) paradigm.(C. Rovee-Collier, 1987; C. K.

Rovee-Collier & Gekoski, 1979) In the RCM paradigm an infant's leg is tethered to an overhead mobile to make the mobile move when the infant kicks. Movement of the mobile in response to the infant's kicks, positively reinforces an infant to increase the frequency of the kicks. Findings from the RCM paradigm suggests that infants as young as 2 months of age can learn and remember to kick more with the leg that is tethered to an overhead mobile compared to the untethered one as the tethered leg makes the mobile move.(Campanella & Rovee-collier, 2005; DeFrancisco & Rovee-Collier, 2008; Hartshorn & Rovee-collier, 1997; Hsu, Rovee-Collier, Hill, Grodkiewicz, & Joh, 2005; Rovee-collier, 2016) Infants' ability to learn the association between their leg movements and the mobile provided a premise for researchers to modify the original mobile paradigm and learn about the kinematics and motor control properties of infant's leg movements. The modern mobile paradigm developed by combining technology and the traditional mobile paradigm together is more challenging and complex where infants are required to kick above a virtual threshold in a specific movement pattern. In the modern mobile paradigm infants need to modify their typical kicking response of the hip and knee moving in a single unit to a pattern that requires the hip to move in flexion and knee in extension.(Y. Chen, Fetters, Holt, & Saltzman, 2002; Sargent, Reimann, Kubo, & Fetters, 2015; Sargent, Scholz, Reimann, Kubo, & Fetters, 2015; Sargent, Schweighofer, Kubo, & Fetters, 2014) This adaptation in the typical kicking response of infants was introduced to assess if infants could discover through their routine play the need to change their lower limb control and make this changes to receive the positive reinforcement. The modern mobile paradigms have incorporated various intrinsic (additional body weights) and extrinsic constraints such as temporal and spatial constraints to detect the changes in the limb and joint coordination as expected while performing a novel task.(Angulo-kinzler & Horn, 2001; Y. Chen et al., 2002; Watanabe & Taga, 2009) It is important to note that there exist a key difference between the classical and operant conditioning paradigms, in operant conditioning the behavioral response is under volitional control as opposed to the reflexive control in classical conditioning. Thus, operant conditioning is a higher behavioral principle than classical conditioning.

Operant conditioning and associative learning paradigms in infants. Tarabulsy, Tessier & Kappas(Dunst, Bruder, Trivette, & Hamby, 2006; Tarabulsy et al., 1996) suggested that a behavior based association is developed when infants learn the association between their own behaviors and influences on the environment. Infants' ability to learn the association between their kicks to the movement of a mobile is an example of a behavior based association. Learning paradigms developed to measure behavior based associations, pairs a behavior of interest with a purpose that is measurable. For eg: The RCM and the modern mobile paradigm pairs the kicking behavior of infants with an overhead mobile. It consists of a baseline phase where the movement of the mobile is not associated with infant's kicks. This phase is followed by the acquisition phase where the mobile moves when the infant kicks. Both traditional and modified mobile paradigms have been extended to assess learning abilities of infants with or at risk of developmental delays.(C. Y. Chen, Harrison, & Heathcock, 2015; Jill C Heathcock, Bhat, Lobo, & Galloway, 2004b, 2005; Me & Heathcock, 2005; Sargent, Kubo, & Fetters, 2017) Findings from these paradigms suggests that infants as young as 2 months of age can discover, learn and remember the association between their kicks and activation of an overhead mobile.(Y. Chen et al., 2002; Jill C Heathcock et al., 2005; C. K. Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980; Sargent, Reimann, et al., 2015) During the associative learning process infants kick at a higher rate to receive the positive reinforcement of making the mobile move.(Dunst, Trivette, Raab, & Masiello, 2008; C. K. Rovee-Collier & Gekoski, 1979) The modern mobile paradigm has provided the evidence on infants ability to change their hip-knee-ankle coordination patterns and select a pattern that keeps the mobile ON for a long period of time.(Y. Chen et al., 2002; Sargent, Reimann, et al., 2015; Sargent, Scholz, et al., 2015; Sargent, Schweighofer, Kubo, & Fetters, 2014a; Sargent et al., 2014) An adaptation of the RCM paradigm is used to assess if infants can associate the movement of their arms with the mobile by tethering infant's wrist to the mobile. Paradigms developed to assess infants' ability to associate their arm movements with the mobile suggest that during the associative learning process infants learn to reduce the degrees of freedom of the arm that is tethered to the mobile and move the arm in a specific pattern that makes the mobile move.(Watanabe & Taga, 2009, 2011)

Technology and Learning-Based Interventions in Infants

The paradigms discussed in the above section suggests that a variety of infant behaviors can be encouraged by pairing it with positive or negative reinforcements. At Research Summit IV "Innovations in Technology for Children with Brain Insults: Maximizing Outcomes" hosted by the Academy of Pediatric Physical Therapy of the APTA, an expert in the field of rehabilitation science, asserted that, "*in order to maximize motor gains and clinical outcomes, researchers must design and test innovative and targeted interventions tailored to the individual child".*(Christy et al., 2016) Developmental researchers combine technology with operant conditioning to assess motor learning and optimize interventions. I propose that innovative technology can be developed that holds the potential to assess infants' ability to demonstrate associative learning in prone and utilize the principles of motor learning for intervention. In order to assess associative learning in prone, technology need to create an environment that provides positive reinforcement to infants' exploratory movements in prone such as pushing the upper body up to look around and explore. As suggested by the DST, *"for a change to occur in* *any developmental system, the system should lose stability for new patterns to develop”.*(Thelen, 1995a) Infants in prone position turn their head to a side to breathe freely and often get "stuck" in that prone motor skill due to the biomechanical constraints imposed by their head size and weak neck muscles. Based on the principles of motor learning and operant conditioning, believe by using technology to provide positive reinforcement to infants’ initial efforts to play in prone there potential for improving time spent and quality of prone play. For infants to progress their prone motor skills there is a need to utilize the principles of motor learning and set goals that are not too easy or too difficult for the infant to the achieve. Consistent with motor learning theory and shaping, the “Just Right” challenge may allow for regular success and feedback on meeting an intermediary goal while working towards an ultimate goal. Technology holds the potential to deliver such targeted intervention. The use of technology combined with a training protocol may also facilitate the individualized challenge of the intervention.

Infants learn through their interaction with the environment. Motor learning and associative learning can be coupled in infancy through training. While there is limited evidence of the use of these devices and protocols as intervention tools, theoretical frameworks provide a foundation for such innovations.

In the next three chapters I have highlighted 1) the process of building and pilot testing a intervention 2) The feasibility of an intervention that is guided by principles of associative and motor learning and 3) Our findings from a protocol developed for the assessment of associative learning in prone.

Paper 1: Prone Play Activity Center – An Instrumented Play Gym to Assess and Enhance Prone Motor Learning in Infants: Conception, Iteration and Innovation

Today, advances in technology have empowered movement specialists to build rehabilitation devices that have the potential to assess and optimize functions. From sensor onesies(Rogers, Polygerinos, Walsh, & Goldfield, 2015) designed to promote early movements in infants with developmental delays to exoskeletons such as Hybrid Assistive Limb Cyberdyne(Matsuda, Mataki, & Mutsuzaki, 2018) developed to promote locomotion in individuals with spinal cord injury, technology has shown promise in adapting to our growth and functional abilities. Two objectives were set for this study: (a) build an assessment tool with the use of technology to quantify associative learning in prone (b) conduct pilot studies to develop a protocol to assess associative learning in prone and develop an intervention program. Four pilot studies were conducted that included the development of the PPAC, test AL protocols used in the mobile paradigms studies to quantify AL in prone, set criteria to identify infants who learned the association in prone, and develop guidelines for an intervention program to encourage prone motor skills. Findings from the preliminary work led to two independent but related studies.

Paper 2: Feasibility of High and Low Tech Interventions to Enhance Motor Development and Prone Tolerance in 3-6 Months Old Infants: A Randomized Trial

Prone play is important for infants to develop strength and coordination in the muscles of the neck, trunk and upper extremities. Encouraging prone play in infants' routine is important to avoid the risks of plagiocephaly and motor delays. Two research questions were examined in this study: (a) to assess the feasibility of a clinical trial comparing usual care (low tech) to a high tech intervention based on the principles of OC and (b) to explore factors that may influence prone motor skills during the intervention period and need to be considered in the potential mechanism of action in future efficacy studies. Findings from this study were needed to determine if larger scale research on the intervention was warranted and feasible.

Paper 3: A Motor Learning Paradigm Combining Technology and Associative Learning to Assess Prone Motor Learning in Infants

Assessment of associative learning in prone position in infants is important to understand the motor learning properties of infants' prone motor behaviors. Two research questions were examined in this study: (a) Can infants demonstrate short term learning of an association between their upper body movements with the activation of a toy while in prone position and (b) retain the association learned on day 1, 24 hours later. The findings from this study were needed to critically evaluate the ability of infant to learn an association in prone in order to determine if this learning strategy could be used in future intervention studies.

Chapter : 2

Prone Play Activity Center – An Instrumented Play Gym to Assess and Enhance Prone Motor Learning in Infants: Conception, Iteration and Innovation

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Abstract

Advances in technology have empowered movement specialists to build rehabilitation devices that have the potential to assess and optimize movement and function in infants. The broader goals of our research are to 1) understand the learning mechanisms underpinning the development of prone motor control in both typically developing infants and infants with developmental delays and 2) develop interventions to improve their tolerance for prone play and positively impact motor development. Through a combination of principles of motor leaning with technology, we have developed the Prone Play Activity Center (PPAC). The purpose of this paper is to present the rationale behind why preliminary work was needed to develop the PPAC. Second, discuss findings from the preliminary work done to develop a functional prototype, set protocols to assess associative learning in prone and develop an intervention program to improve prone tolerance and prone motor skills.

Key words: Prone, Prone play, Associative learning, Rehabilitative technology

Introduction

The broader goals of our research are to 1) understand the learning mechanisms underpinning the development of prone motor control in both typically developing infants and infants with developmental delays and 2) develop interventions to improve their tolerance for prone play and positively impact motor development. Rehabilitation devices have the potential to both assess and optimize infant movement and functions. From sensor onesies[1] designed to promote early movements in infants with developmental delays to exoskeletons such as Hybrid Assistive Limb - Cyberdyne[2] developed to promote locomotion in individuals with spinal cord injury, technology has shown promise in adapting to our growth and functional abilities. At Research Summit IV "Innovations in Technology for Children with Brain Insults: Maximizing Outcomes" by American Physical Therapy Association[3],physical therapy (PT) researchers were encouraged to conduct studies that utilizes the advances in technology to enhance the effectiveness of PT assessments and interventions for child development and learning. In line with the suggestions by APTA, we have instrumented a device - Prone Play Activity Center (PPAC) developed to achieve our research goals. PPAC is based on the principles of associative learning described as the ability to discover causal relationships between two or more events.[4,5] Infants as young as 8 weeks of age have demonstrated the ability to understand the association between their kicks and the activation of an overhead mobile.[5–11] The construct of associative learning extends to the principles of operant conditioning according to which a behavior can be encouraged by associating it with a positive experience or reinforcement.[5,7,12] Encouragement of motor behaviors in infancy through positive reinforcement is not a new concept and has been utilized to increase sucking, vocalization, kicking and reaching in both typically developing infants and infants with motor delays.[7] For instance, by using a pacifier that plays the voice of the infant's mother when sucked at a certain pressure, physical therapists and nurses in the NICU were able to improve the rate of sucking and feeding outcomes in infants born preterm and facilitate early discharge.[13,14] In another study, toys that moved and sounded only upon contacts encouraged 3 months old infants to contact more and practice reaching and object exploration.[15] With a strong proof of concept provided by studies that have used operant conditioning to modify motor behaviors, we aim to teach infants to change in their prone motor behavior. In this paper, first we would present the rationale behind why preliminary work was needed. Second, discuss findings from the preliminary work done to develop a functional prototype, set protocols to assess associative learning in prone and develop an intervention program to improve prone tolerance and prone motor skills.

Methods

Areas of uncertainty: rationale for preliminary work. To our knowledge associative learning has never been tested in prone position in infants. Motor behaviors that have been studied most commonly with the use of associative learning paradigms in infants are kicking and reaching.[5] These behaviors share some properties such as infants early in development move their upper and lower limbs spontaneously in a rhythmic manner.[16] The mobile paradigm originally developed with kicking as the behavior of interest was adapted to understand the skill of reaching in infants.[17] However, with limited research on the mechanics of infant's prone motor behaviors, adaptation of the mobile paradigm in prone in itself was a challenge. Assessment of associative learning in prone required us an artificial environment where infant's prone motor behavior is precisely associated with an effect. Use of movement sensors seemed to be a plausible option for building a device that can associate infants' upper body movements in prone with a positive reinforcement. Some common factors identified in the literature that are responsible for the decline of technology in pediatric rehabilitation are the technology being bulky, not aesthetically pleasing, parents feel their child is wired up and the child grows out of it.[3] It was important to build a device that is parent and child friendly which would, in theory, lead to better parent and child adherence as compared to older systems. The goals of the preliminary work were to: (1) build an assessment tool to assess the construct of associative learning in prone; (2) use pilot data from the device to define the learning criteria to categorize individual infants as learners and non-learners; (3) start to determine whether infants can learn the association between lifting their head to a certain level and activate a toy; (4) validate the Matlab code developed to process and analyze the data; and (5) determine the "just right" prone play level for infants with poor tolerance for prone play.

Pilot 1: Development of the prone play activity center. To assess associative learning in pronelying in 3-6 months old infants, we built the "Prone Play Activity Center" (PPAC) through a series of three iterations. During the iterative processes two different types of sensors were evaluated and sensor validation was completed. For our first iteration we used one infrared sensor, mounted above the infant's head to locate head position in space (Figure 1a). We pilot tested the first iteration on 4 full term healthy infants, 3 – 6 months of age. During pilot testing, we found a delay in the sensitivity of the sensor to activate a toy when infants' raised their head to a certain height. We observed that above a certain height the sensor would not sense infants' head position in space. Insensitivity of the infrared sensor suggested the sensors' sensing area being too small. Most sensors have a detection area that is cone shaped. If the conical detection area of the sensor is not wide enough, the infant's head will move out of the sensor area as infants are raising their head in prone higher and getting closer to the sensor in prone. To resolve the issue of insensitivity of the infrared sensor we switched to three ultrasonic sensors during 2nd iteration testing (Figure 1b) and mounted the sensors to a height, high enough to provide a wide cone shaped sensor area in the 3rd iteration (Figure 1c). The final iteration of the PPAC was tested on 3 infants to finalize the following components for the future experiments (Figure 1c): 1) ultrasonic sensors 2) Arduino Uno microcontroller 3) dancing/singing toy. The sensors locate the position of infants' head in space and records the heads' distance from the floor (HH) every 90 milliseconds (msecs). The microcontroller compares the HH to the controller settings and activates the toy if conditions are met. For example, if the microcontroller is set to activate the toy when the infant's head is $\geq$ 10 cm off the floor, the toy will turn on when the head is $\geq$10 cm and turns off when the infant lowers his head to < 10 cm. The PPAC has two modes: 1) Continuous mode 2) Interval mode. In the continuous mode the toy will activate when the infant's head is at or above the threshold and will turn off when the infant's head is below the threshold. In the interval mode, the same conditions must be met to turn the toy on, but the toy will turn off after a certain period of time or interval length even if the infant's head is above the threshold or when the infants head goes below the threshold, which ever happens first. For example. For example, if the interval mode is ON and is set at 10 seconds. The toy will activate when the infant's head is at or above the threshold (AT) and will turn off when the infant is below the threshold or after 10 seconds of time with the toy on, even if the infants head is above the threshold. To reactivate the toy, the infant needs to lower her/his head and then raise her/his head to the threshold again. The microcontroller is connected to a computer that records the following data every 90 msecs: (1) Head lift height (HH), distance from the highest point on the infant's head to the floor; (2) Average head lift height (AHH), average HH during the trial; (3) Frequency of infant achieves AT (FAT); (4) Total duration the infant achieves AT; and the (5) total duration the PPAC toy was on (DTO) (refer to Table 1 for description of additional terms that were calculated from the raw data acquired from the PPAC).

Pilot 2: development of the associative learning criteria. Four infants were tested with a variety of associative learning protocols to assess the feasibility of each protocol, determine the ideal length of each testing phase and establish the height at which the threshold should be set. Consistent with the Rovee-collier mobile paradigm[5,6] we started out testing a 2 minute baseline, and 10 minute acquisition. However, all 4 infants could not complete the 12 minutes of testing (2 min baseline plus 10 minute acquisition phase). By the end of the 9th minute in a 10 minutes learning trial, infants were crying or fussing and there was a decrease in their head lift height, suggesting fatigue. When an infant did not complete the full testing all their data was lost. So, we opted for an 8 minutes learning trial and divided it in 4, 2 minutes blocks with a 10 second rest period between the blocks in order to allow us to capture each block individually. Figure 2 represents the final, 2 consecutive days of testing protocol. Day 1 of testing consists of a 30 seconds pre-baseline phase followed by a 2 minutes baseline and 8 minutes of acquisition phase. In the pre-baseline phase, infants were positioned prone lying in the PPAC for 30 seconds. At the end of the 30 seconds, the PPAC calculated the AHH. The AHH was used to set the TH due to the following reasons: (1) if the threshold is too high the infant may not activate the toy frequently enough during the learning trial to determine that it is his/her act of lifting the head that is activating the toy; and (2) if the threshold is too low the infant may activate the toy once and not be able to reactivate the toy considering the high eccentric control required to lower the head and upper body below the level of the threshold. Thus, a too high or a too low threshold may fatigue the infant and interrupt the associative learning process. In the Baseline phase, infants were positioned in prone in the PPAC for 2 minutes. The PPAC toy did not activate in response to infants' movements during this period. The purpose of the baseline phase was to provide information about the infants' head lift height not associated with the activation of the PPAC toy. In the Acquisition phase, the PPAC toy was activated in response to an infant's raising his/her head to a height equivalent to or greater than the TH. The toy remained on for a maximum of 10 seconds or turned off anytime the infants' head was below the AT. We included the "10 seconds rule" as we found infants would hold their head up at or above the TH to keep the toy ON for the whole acquisition period and will not have the opportunity to explore the association between their movement and the toy activation. While this protocol is different than the traditional associative learning paradigm with the use of blocks rather than continuous practice as during our pilot testing we observed that by providing intermittent breaks between the acquisition phase most of the infants completed the acquisition phase of testing.

Pilot 3: Testing the planned associative learning protocol. Five infants, 3-6 months old were tested in the PPAC for associative learning using the proposed protocol (see procedure section below for details). Data from these infants were used to set a priori learning and retention criteria for the proposed study. Table 2 and Figure 3 represents the baseline and learning trial data for an infant tested during pilot work 3. In Figure 3, note how the infant is holding her head at various heights during the baseline and 1st acquisition, but then holds the head right around the TH that activates the toy in 2nd and 3rd acquisition blocks. In addition, during testing the toy was set at a 10 second interval length. The toy would turn off after 10 seconds even if the infant is maintaining her head AT. The infant had to cross the TH again to activate the toy. During the baseline and 1st block of acquisition the Frequency of toy reactivations (FTR) (see Table 1 for term definitions) is 2 but by the 2nd block of acquisition the FTR's are at 7. Thus, by the 2nd block of acquisition there is 3.5 times increase in the FTRs. So, by 2nd block of acquisition the infant is activating the toy, maintaining the head at the TH and reactivating the toy after 10 seconds.

In the process of deciding the associative learning and retention criteria for the proposed study we analyzed our preliminary data from the 5 infants using multiple criteria that are either present in the literature or are based on our understanding of the paradigm.(refer Table 1) The Rovee Collier learning criteria[5,6] categorizes an infant as a learner of the mobile paradigm if the infant's frequency of kicks for any two consecutive 2 minutes during acquisition is 1.5 times greater than the within day baseline kicking frequency. Translating the Rovee Collier criteria into the prone paradigm an infant would need to lift their head 1.5 time more than baseline for 4 minutes. None of the five infants learned our paradigm. With the Rovee Collier learning criteria we are only taking into consideration the frequency of AT. However, the motor pattern for kicking is highly repetitive and there is not a duration associated with the response, as a single kick activated the mobile and the mobile stopped when the kicking stopped. We believe that infants who will learn our paradigm will not only learn to activate the toy but also keep the toy ON for a longer period and reactivate it when it turns off. This can be calculated using the duration the toy was ON at the end of each trial (DTO) and FTR being the dependent measures.

Associative learning and retention criteria in prone. Based on the pilot testing results we established a criteria to quantify learning using the PPAC. Individual infants were categorized as short term learners if their FTR and DTO in any 2 consecutive phases of the final 3 acquisition phases was 1.5 times higher than the FTR and DTO of the baseline on day

1.Retention of the association learned on day 1 was identified if infants FTR and DTO in any 2 consecutive phases of the final 3 acquisition phases on 2^{nd} day of testing was 1.5 times the FTR and DTO of the baseline phase on day 1. Pilot 3 confirmed the adequacy of the testing protocol as we were able to capture change seen in the FTR and DTO between the baseline and acquisition phase of testing. Our ability to use the PPAC successfully to assess associative learning on all 5 infants who participated in pilot 3, verified the feasibility of using PPAC to follow the testing protocol.

Pilot 4 Matlab code developmental and validation. The purpose of pilot 4 was to validate the Matlab code developed to calculate the FTRs and DTOs. The FTRs and DTOs are the parameters used to categorize infants as learners and non-learners. Data of the 5 infants in pilot 3 was processed using 2 methods: Manual and Matlab. The manual method involved the use of functions in Microsoft Excel to clean the raw data and block the segments where the infant re-activated the toy after the toy had been activated for the whole IL by the infant (10 seconds used in the protocol). These segments were counted to determine the FTRs. To calculate the DTOs the block of time when the infant activated the toy determined by the head height above the threshold height was marked and summed for the total duration. The manual method was time intensive as the size of each data file ranged from 400-600 KB. The manual method also required multiple checks to ensure accuracy. To improve the efficiency of our data processing method a Matlab code was developed. To validate the Matlab code we compared the FTRs and DTOs calculated manually to the data calculated by the Matlab code. We found a 100% agreement between both the methods of data processing and decided to use the Matlab code, which is a more time efficient method to process big data files.

Pilot 5: Defining the intervention protocol. The purpose of pilot 5 was to operationally define the "just right" level of prone play for infants with poor tolerance of prone position. This was required to guide our intervention developed to support motor development and prone tolerance during infancy. The "just right challenge" of play is described in the literature as setting a play environment that is not too easy or too difficult for infants to learn and advance their skills.[18–20] For example: to encourage exploration and reaching in an infant who has visual difficulties, the "just right" level to introduce objects would be at the level of the eye, so not too close to the eye or too far from it, for the infant to reach and interact. The "just right" level of prone play would guide parents during the intervention period to set the threshold at which infants will be able to activate the toy in the PPAC. With this pilot work we wanted to operationally define three levels of prone play – easy, moderate and challenging. Based on the mobile paradigm studies, the AHH would be considered to be an "easy" level of prone play; however, we selected the AHH to be a "moderate" level as infants who could tolerate prone play well could not stay at the AHH in the PPAC for more than 8-10 minutes per session (pilot 2-3). Since the intervention guidelines asked parents to begin at the easy level and practice prone play for at least 30 minutes/day (paced in 4-5 sessions if needed) it would be challenging for parents to comply with the intervention guidelines if the AHH was selected as the easy level of prone play. We decided the easy level to be below the AHH and standardized it to be 25 % below the AHH. The AHH of 3-6 months old infants who participated in pilot 3 was at the range of 8 – 12 inches. The easy level of prone play for an infant with an 8 inches of AHH would be 6 inches. Any AHH below 6 inches will make the PPAC sensors less sensitive towards infant's head position and movements as the sensors captures the head position at its best from 5 – 17 inches above the floor. Thus, three "just right" levels of prone play were decided based on our findings from pilot 1-3: Easy = 25% below the AHH, Moderate = AHH and Challenging = 25 % above the AHH.

Discussion

The preliminary work supported the conception of an instrument play gym that can be used to assess associative learning in prone and develop interventions based on operant conditioning. Through multiple testing, we were able to determine an assessment protocol that is feasible to administer in infants. Findings from the preliminary work were used to conduct two research projects discussed in chapter 3 and chapter 4.

References

1. Rogers E, Polygerinos P, Walsh C, Goldfield E. Smart and Connected Actuated Mobile and Sensing Suit to Encourage Motion in Developmentally Delayed Infants [1]. *J Med Device*. 2015;9(3):30914. doi:10.1115/1.4030550

2. Matsuda M, Mataki Y, Mutsuzaki H. Immediate effects of a single session of robot-assisted gait training using Hybrid Assistive Limb (HAL) for cerebral palsy. 2018:207-212.

3. Christy JB, Lobo MA, Bjornson K, et al. Technology for children with brain injury and motor disability: ExecutIVe summary from research summit IV. *Pediatr Phys Ther*. 2016;28(4):483-489. doi:10.1097/PEP.0000000000000317

4. Reeb-Sutherland BC, Levitt P, Fox NA. The predictive nature of individual differences in early associative learning and emerging social behavior. *PLoS One*. 2012;7(1). doi:10.1371/journal.pone.0030511

5. Rovee-Collier C. Learning and memory in infancy. In: *Handbook of Infant Development (2nd Ed.). Wiley Series on Personality Processes*. ; 1987.

6. Rovee-Collier CK, Gekoski MJ. The economics of infancy: a review of conjugate reinforcement. *Adv Child Dev Behav*. 1979;13:195-255.

7. Gerhardstein P, Kraebel K, Tse J. Using operant techniques with humans infants. *Behav Anal Today*. 2006;7(1):56-70. http://www.biomedsearch.com/article/Using-operant-techniques-with-humans/170113005.html.

8. Sargent B, Schweighofer N, Kubo M, Fetters L. Infant exploratory learning: Influence on leg joint coordination. *PLoS One*. 2014;9(3). doi:10.1371/journal.pone.0091500

9. Sargent B, Kubo M, Fetters L. Infant Discovery Learning and Lower Extremity Coordination: Influence of Prematurity. *Phys Occup Ther Pediatr*. 2017;2638:1-16. doi:10.1080/01942638.2017.1357065

10. Sargent B, Reimann H, Kubo M, Fetters L. Quantifying Learning in Young Infants: Tracking Leg Actions During a Discovery-learning Task. *J Vis Exp*. 2015;(100):e52841. doi:10.3791/52841

11. Heathcock JC, Galloway JCC. Movement in Infants Born Preterm : *Phys Ther*. 2009;89(10):1-12.

12. Tarabulsy GM, Tessier R, Kappas A. Contingency detection and the contingent organization of behavior in interactions: Implications for socioemotional development in infancy. *Psychol Bull*. 1996;120(1):25-41. doi:10.1037/0033-2909.120.1.25

13. Standley JM. The effect of music-reinforced nonnutritive sucking on feeding rate of premature infants. *J Pediatr Nurs*. 2003;18(3):169-173. doi:10.1053/jpdn.2003.34

14. Chorna OD, Slaughter JC, Wang L, Stark AR, Maitre NL. A Pacifier-Activated Music Player With Mother's Voice Improves Oral Feeding in Preterm Infants. *Pediatrics*. 2014;133(3):462-468. doi:10.1542/peds.2013-2547

15. Williams JL, Corbetta D. Assessing the impact of movement consequences on the development of early reaching in infancy. *Front Psychol*. 2016;7(APR):1-15. doi:10.3389/fpsyg.2016.00587

16. Thelen E. Motor development. A new synthesis. *Am Psychol*. 1995. doi:10.1037/0003-066X.50.2.79

17. Taylor HB, Barnes MA, Landry SH, Swank P, Fletcher JM, Huang F. Motor contingency learning and infants with spina bifida. *J Int Neuropsychol Soc*. 2013;19(2):206-215. doi:10.1017/S1355617712001233

18. Dusing SC, Tripathi T, Marcinowski EC, Thacker LR, Brown LF, Hendricks-Muñoz KD. Supporting play exploration and early developmental intervention versus usual care to enhance development outcomes during the transition from the neonatal intensive care unit to home: a pilot randomized controlled trial. *BMC Pediatr*. 2018;18(1):46. doi:10.1186/s12887-018-1011-4

19. Honeyford MA, Boyd K. Learning Through Play. *J Adolesc Adult Lit*. 2015;59(1):63-73. doi:10.1002/jaal.428

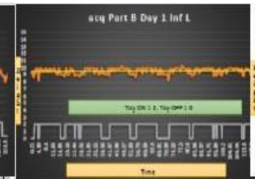
20. Rebeiro KL, Polgar JM. Enabling occupational performance: Optimal experience in therapy. *Can J Occup Ther*. 1999;66(1):14-22.

Tables

Table 1: Terms and abbreviations used in the protocol

Term (abbreviation)	Definition	How obtained/calculated
Head lift height (HH)	Distance from the highest point on the infant's head to floor.	Calculated by the PPAC
Average head lift height (AHH)	Infant's average head lift height during the trial.	Calculated from the data from PPAC
Threshold height (TH)	Height set by the experimenter at which the toy turns ON.	Equals AHH during the Pre-baseline trial
At or Above Threshold (AT)	Infant's head is equal to or higher than a threshold height	
Frequency of AT (FAT)	Number of times infant achieves AT	Calculated of the data from PPAC
Duration AT (DAT)	Duration of an episode of AT during the trial	Calculated of the data from PPAC
Total DAT	Sum of all DAT during the trial	Calculated of the data from PPAC
Average DAT	Average duration of time infant achieves AT during the trial	Total DAT /FAT
Interval Length(IL)	Maximum duration of toy activation per AT	Set by the experimenter during the Interval mode
Duration of Toy ON (DTO)	Duration of a continuous episode of AT during the trial with a maximum equivalent to the IL.	DTO = DAT with a maximum of IL
Frequency of toy reactivations (FTR)	Frequency of reactivations after meeting the IL	Matlab was used to calculate the FTR
Learning criteria		
Frequency based learning criteria		FTR_baseline*1.5 <FTR_AQ (any 2 of the final 2 acquisition phases)
Duration based learning criteria		DTO_baseline*1.5 < DTO_AQ(any 2 of the final 3 acquisition phases)

Table 2: Preliminary associative learning data



Infant L Day 1 data	Baseline	AQ_1	AQ_2	AQ_3	AQ_4
Trial length (TL)[a]	120 s	120 s	120 s	120 s	120 s
AHH[a]	8.6"	8.9"	9.5"	9.3"	7.3"
FAT (TH =9)[a]	10	25	15	8	9
Total DAT [a]	53	81	114	106	34
Average DAT[a]	5.3	3.24	7.6	13.25	3.7
DTO[a]	38s	55 s	82 s	60 s	27 s
Frequency of toy reactivations[a]	2	2	7	7	2
Duration based learning criteria[a]	38 * 1.5 = 57 s	No	Yes	Yes	No
Frequency based learning criteria[a]	2 * 1.5	No	Yes	Yes	No
Rovee Collier mobile paradigm criteria [25] - FAT baseline* 1.5 > for any two consecutive 2 minutes during acquisition	10 * 1.5	Yes	No	No	No
TDAT_baseline*1.5	53 * 1.5 = 79.5	Yes	Yes	Yes	No
Proportion of DTO/TDAT baseline * 1.5	38/53 * 1.5 = 1.07	55/81 = .68 No	82/114 = .72 No	60/106 = .28 No	27/34 = .79 No
Behavioral state	Alert and active	Alert and active	Alert and active	Alert and active	Crying

Figures

1a

1b

1c

Figure 1: Three iterations of the Prone Play Activity Center (PPAC)

Day 1	Prebaseline (30 seconds)	Baseline (2 minutes)	Acquisition (AQ) (8 minutes)			
			AQ_1 (2minutes)	AQ_2 (2minutes)	AQ_3 (2minutes)	AQ_4 (2minutes)
Day 2			Acquisition (8 minutes)			
			AQ_1 (2minutes)	AQ_2 (2minutes)	AQ_3 (2minutes)	AQ_4 (2minutes)

Figure 2: Associative learning in prone testing protocol

Appendix A

Prone play activity center – Matlab code

```
%----------------------------------------------------------------------
%
%
%  This program is designed to (1)plot PPAC data, (2)allow the user to
%  select data to be processed,and (3)plot, compute, and store appropriate
%  performance metrics.
%
%  Pidcoe 042617
%----------------------------------------------------------------------

clear all                          %clear all variables
close all                          %close all windows and files
prgm = sprintf('PROGRAM = PPAC3.m');       %program name for storage files
% sampling_rate = 250;                    %set to 250Hz
% T = 1 / sampling_rate;                  %period
PLOT = 1;                              %set plotting flag

%----------------------------------------------------------------------
%  query input file name
%----------------------------------------------------------------------
root_name=input('Select File to Run: ','s');
in = strcat(root_name, '.asc');  % append extension
%OPEN FILE
fid = fopen(in);           %open file
C = fread(fid);            %read array
D = C';                    %transpose column to row

%----------------------------------------------------------------------
%  create output file
%----------------------------------------------------------------------
out=strcat(root_name,'.out');   %open a file to store % activation results
fid_out = fopen(out, 'w');
fprintf(fid_out,'%s\r\n',prgm); fprintf(fid_out,'\r\r\n');
fprintf(fid_out,'FILE = %s\r\n',strcat(root_name,'.txt'));
fprintf(fid_out,'\r\n');

%----------------------------------------------------------------------
%  FIND 'RESETTING...' string
%----------------------------------------------------------------------
   r = findstr(D,'Resetting System...');   %search for start of trial
   s = findstr(D,'time2=');               %search for beginning of data

%----------------------------------------------------------------------
%  FIND 'TIME2=' string AFTER RESETTING... string
```

```
%------------------------------------------------------------------------
   start = zeros(length(r),1);
   for i=1:length(r)
      for j=1:length(s)
         if s(j) > r(i)
            start(i) = s(j);
            break;
         end
      end
   %    fseek(fid,r(i)-1,'bof'); %move to reset string location
   %    s = findstr(D,'time2='); %search for beginning of data
   %    start(i) = s(1);         %store first element
   end

%------------------------------------------------------------------------
%  DETERMINE LARGEST ARRAY SIZE (and store each file length)
%------------------------------------------------------------------------
   frewind(fid);
   i = 1;
   max = 0;
   SIZE = zeros(99,1);     %store the size of each trial
   while ~feof(fid)
      fseek(fid,start(i)-1,'bof');
      ftell(fid);
      [T, position]=textscan(fid,'%s %f %s %s %d %s %s %f %s %d %s %d %s %d');
      SIZE(i) = length(T{1,1});
      if SIZE(i) > max
         max = length(T{1,1});
      end
      i = i+1;
   end

%------------------------------------------------------------------------
%  INITIALIZE STORAGE ARRAYS
%------------------------------------------------------------------------
   xtime = zeros(max,i-1);
   trig  = zeros(max,i-1);
   crnt  = zeros(max,i-1);
   iflag = zeros(max,i-1);
   RAW_iflag = zeros(max,i-1);
   idur  = zeros(max,i-1);
   itime = zeros(max,i-1);

%------------------------------------------------------------------------
%  RECOVER DATA INTO MATRICES - note varying lengths and zero padding
%------------------------------------------------------------------------
   frewind(fid);
   i = 1;
   while ~feof(fid)
      fseek(fid,start(i)-1,'bof');
```

```
    ftell(fid);
    [T, position]=textscan(fid,'%s %f %s %s %d %s %s %f %s %d %s %d %s %d');

    %have to transfer one at a time due to file length differences
    for j=1:length(T{1,2})-1
      xtime(j,i) = T{1,2}(j,1);
      trig(j,i)  = T{1,5}(j,1);
      crnt(j,i)  = T{1,8}(j,1);
      RAW_iflag(j,i) = T{1,10}(j,1);

      if (T{1,10}(j,1) == 2)  %create ON/OFF plotting array
        iflag(j,i) = 2;
      else
        iflag(j,i) = 0;
      end

      idur(j,i)  = T{1,12}(j,1);
      itime(j,i) = T{1,14}(j,1);
    end

    i = i+1;
  end

TRIALS = i-1;

%-----------------------------------------------------------------------
%  PROCESS DATA - need to loop for the number of trials detected
%-----------------------------------------------------------------------
for k=1:TRIALS
  str = sprintf('TRIAL = %d',k);
  idx = ~isstrprop(str,'wspace'); % detect spaces
  idy = idx | [idx(2:end),true]&[true,idx(1:end-1)]; % ignore single space
  und = char(32*~idy); % define output spaces
  und(idy) = '-'; % add whatever character to use as the underline
  fprintf(fid_out,'\n%s\n\r\r',str) % print
  fprintf(fid_out,'\n%s\n\r\r',und) % print

  %-----------------------------------------------------------------------
  % plot raw data and let user input start and stop points for analysis
  %
  % NOTE that istart and istop are now created from floating point values to
  % increase the resolution of the selection
  %-----------------------------------------------------------------------
  TIME_plot = xtime(5:SIZE(k)-5,k);           %load current time data
  RAW_plot = crnt(5:SIZE(k)-5,k);             %load current distance data
  iflag_plot = iflag(5:SIZE(k)-5,k);          %load iflag data
  RAW_iflag_plot = RAW_iflag(5:SIZE(k)-5,k);    %load RAW toy ON/OFF data
  trig_dist = trig(1,k);                      %load current trigger value
  file_len = SIZE(k)-10;
```

```
if PLOT == 0
   user_begin=1;
   user_end=file_len-1;
end

if PLOT == 1
   scrsz = get(0,'ScreenSize');
   L = scrsz(3)/8;          %left
   B = scrsz(4)/8;          %bottom
   W = scrsz(3) - (2*L);    %width
   H = scrsz(4) - (2*B);    %height
   str = sprintf('TRIAL = %d',k);
   figure('Name',str,'NumberTitle','off',...
      'Position',[L B W H])    %title and position figure

   subplot(2,1,1);             %define subplot area
   hold on
   plot(TIME_plot,RAW_plot,'b')    %plot raw data
   plot(TIME_plot,iflag_plot,'k')  %plot ON/OFF data

   str = sprintf('RAW');
      title(str)
      xlabel('Time (s)')
      ylabel('Head Height (in)')
   y = [trig_dist trig_dist];      %define trigger distance
   plot(xlim,y,'g')                %plot trigger distance

   %graphically locate start and stop points for analysis
   [x,y] = ginput(2);
   user_begin = x(1);
      if (user_begin < 0) user_begin = TIME_plot(1); end
   user_end = x(2);
      if (user_end < user_begin)
        user_end = TIME_plot(file_len+1);
      end
      if (user_end > TIME_plot(file_len+1))
        user_end = TIME_plot(file_len+1);
      end

end

%display selected values
hold on;
   itemp = [user_begin user_begin];
      plot(itemp,ylim,'r');            %ylim = axis limits
   itemp = [user_end user_end];
      plot(itemp,ylim,'r');            %ylim = axis limits

%determine array locations for user_begin and user_end
istart = 0; istop = 0;                 %preset values to 0
```

```
for i=1:file_len+1
   if (TIME_plot(i) >= user_begin && istart == 0)
      istart = i;
   end
   if (TIME_plot(i) >= user_end && istop == 0)
      istop = i;
   end
end

fprintf(fid_out,'\nTotal file length = %.2fsec',...
   TIME_plot(length(TIME_plot)));
fprintf(fid_out,'\n -- Selected data from %.2f to %.2f sec\n\r\r',...
   TIME_plot(istart),TIME_plot(istop));

%-----------------------------------------------------------------------
%  create temporary arrays from indices
%-----------------------------------------------------------------------
a = TIME_plot(istart:istop,1);
b = RAW_plot(istart:istop,1);
c = iflag_plot(istart:istop,1);
d = RAW_iflag_plot(istart:istop,1);

%-----------------------------------------------------------------------
%  compute metrics
%-----------------------------------------------------------------------
% number of toy triggers
freq_cnt = 0;
dur_toyON = 0; tSTART = 0;
for i=2:length(c)
%        sprintf('i = %d  c = %d freq_cnt = %d',i,c(i),freq_cnt)
   if (c(i) == 2 && c(i-1) == 0)  %ON transition
      freq_cnt = freq_cnt + 1;
      tSTART = a(i);
   end
   if (c(i) == 0 && c(i-1) == 2 && tSTART ~= 0)  %OFF transition
      tSTOP = a(i);
      tDIFF = tSTOP - tSTART;
      dur_toyON = dur_toyON + tDIFF;  %duration of toy ON
   end
end
fprintf(fid_out,'\ntrigger total = %d\n\r\r',freq_cnt);

% average head height
fprintf(fid_out,'\naverage head height= %.2f±%.2f\"\n\r\r',...
   mean(b),std(b));

% duration of toy ON
fprintf(fid_out,'\ntrigger height = %.2f\"\n\r\r',trig_dist);
fprintf(fid_out,'\n\tduration of toy ON = %.2fs\n\r\r',...
   dur_toyON);
```

```
% duration of head above trigger
dur_headABOVE = 0; tFLAG = 0;
for i=2:length(b)
   if (b(i) >= trig_dist && tFLAG == 0)  %ABOVE trigger
      tSTART = a(i);
      tFLAG = 1;
   end
   if (b(i) < trig_dist && tFLAG == 1)   %BELOW trigger
      tSTOP = a(i);
      tDIFF = tSTOP - tSTART;
      dur_headABOVE = dur_headABOVE + tDIFF;  %duration ABOVE trigger
      tFLAG = 0;
   end
end

if (tFLAG == 1)     %clean up last above trigger time
   tSTOP = a(i);
   tDIFF = tSTOP - tSTART;
   dur_headABOVE = dur_headABOVE + tDIFF;  %duration ABOVE trigger
   tFLAG = 0;
end

fprintf(fid_out,'\n\tduration of head above trigger = %.2f\n\r\r',...
   dur_headABOVE);

% number of toy time-outs followed by re-triggers
freq_cnt = 0;
tflag = 0;
for i=2:length(d)
   if (d(i) == 3 && d(i-1) == 2)  %time-out (toy OFF transition)
      tflag = 1;
   end
   if (d(i) == 2 && d(i-1) == 0 && tflag == 1)  %re-trigger (toy ON)
      freq_cnt = freq_cnt + 1;
      tflag = 0;
   end
end
fprintf(fid_out,'\nre-trigger total (learning) = %d\n\r\r',freq_cnt);

%-----------------------------------------------------------------------
%  plot data
%-----------------------------------------------------------------------
subplot(2,1,2);                         %define subplot area
   hold on
   title('PROCESSED')
   plot(a,b,'b')
   plot(a,c,'k')
   xlabel('Time (s)'); ylabel('Head Height (in)');
   y = [trig_dist trig_dist];         %define trigger distance
   plot(xlim,y,'g')                   %plot trigger distance
```

```
    %-----------------------------------------------------------------------
    %  fit data with linear regression and plot
    %-----------------------------------------------------------------------
    ftemp = polyfit(a,b,1);          %1st order fit of head height data
    e = zeros(length(a),1);

    for i=1:length(a)                %create and plot arrays
       e(i) = (ftemp(1)*a(i)) + ftemp(2);
    end
       plot (a,e,'r')

    fprintf(fid_out,'\nRegression values are m= %.2f to b= %.2f\n\r\r',...
       ftemp(1),ftemp(2));

    %-----------------------------------------------------------------------
    %  store metrics to file
    %-----------------------------------------------------------------------



    %-----------------------------------------------------------------------
    %  annotate plot
    %-----------------------------------------------------------------------
    str = sprintf('Slope = %s',num2str(ftemp(1)));
    text(mean(a),mean(b)-1,str,'HorizontalAlignment','center')

%     pause

    %-----------------------------------------------------------------------
    %  clear vectors for next iteration
    %-----------------------------------------------------------------------
    clear a;
    clear b;
    clear c;
    clear d;
    clear e;
    hold off;

    fprintf(fid_out,'\n\n\r\r');

    pause;

end
```

Appendix B

Prone Play Activity Center components

Arduino Uno
Display
Protoshield
Relays
Screw terminals
10K potentiometer
Knobs
USB cable
Battery holder
Barrel connector
RCA Panel mnt
RCA Male plugs
Sonar sensors
Fiberglass rods
Cable/wire
3 D print material
Toys

Chapter: 3

Feasibility of High and Low Tech Interventions to Enhance Motor Development and Prone Tolerance in 3-6 Months old Infants: A Randomized Trial

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Abstract

Background: The American Academy of Pediatrics recommends "parents and caregivers incorporate supervised, awake "prone play" in their infant's daily routine to support motor development and minimize the risk of plagiocephaly". **Purpose:** To determine the feasibility of a clinical trial comparing usual care (low tech) to a high-tech intervention to increase tolerance for prone and improve prone motor skills. The proposed high tech intervention has two key elements: (1) providing reinforcement to infants to raise their head above a target threshold to activate a toy; and (2) challenging infants to raise their heads higher each time they achieve a target. **Methods:** Ten full-term infants with poor prone tolerance were randomized to the high-tech or the low-tech, education group. Parents and infants in each group participated in a 3 week intervention with 4 PT visits and 15 parent sessions. Intervention frequency and parent feedback data were used to determine the feasibility of the high-tech intervention. Effect sizes were calculated for motor and prone tolerance measure at baseline and end of intervention. **Results:** Infants received an average of 93% of the anticipated high-tech intervention sessions. Parents had high adherence to one of the 2 key components of the intervention and independently used the high technology for a mean of 18 (7) minutes per day. Effect sizes were large for the motor development and prone tolerance measures and in the anticipated direction. **Conclusion:** The proposed high-tech intervention is found to be feasible and appropriate for a future large-scale clinical trial.

Key words: Prone tolerance, prone motor skills, prone play, high-tech intervention, prone play and technology.

Introduction

The American Academy of Pediatrics (AAP) recommends that “parents and caregivers should incorporate supervised, awake “prone play” in their infant’s daily routine to support motor development and minimize the risk of positional head deformities.”[1],[2] However, approximately 70% of 4-5 months old infants are spending more time in supine, supported sitting or being held (x = 8.9 hours, SD = 1.26) compared to prone position (x = 1.2 hours, SD = 1.1) during the day.[3] It was estimated that 20 % of infants 4 million infants born in 2013 would experience some degree of positional skull deformation.[4] Studies have suggested excessive supine lying (β= 2.8; 95% CI: 2.23– 3.32) and limited prone play time (β = .9; 95% CI: 1.53–0.22) in infants’ routine as factors associated with the risk of positional plagiocephaly.[5,6]

Infants’ poor tolerance for prone position, biomechanical challenges imposed by prone on the musculoskeletal system and parents’ hesitation towards prone play likely lead to minimal practice of motor skills in prone (Figure 1). According to the ecological theory of motor learning, practice along with knowledge of performance (feedback received during the movement) and knowledge of results (feedback received after the movement) is beneficial for motor learning.[9] For infants to develop prone motor skills it is necessary to gain strength through practice.[8] Due to infants’ intolerance for prone lying, parents, including those familiar with AAP’s “back to sleep and prone to play” recommendations, find it challenging to incorporate prone play in their infant’s daily routine.[3,7]

Current approaches to increase prone motor skills and improve tolerance for prone play include educating parents through brochures and using commercially available prone positional supports such as U shaped pillows and play gyms. Lack of scientific rigor in the prone play recommendations leads to poor implementation of prone play during infancy as health care providers and parents are not clear about the guidelines.[12] To our knowledge, there are no studies done on the efficacy of play-based intervention programs developed to improve tolerance for prone and prone motor skills of infants.

While healthy typically developing infants are at risk of mild developmental delays and plagiocephaly due to limited prone play, a larger impact is seen on infants with a pre-existing risk of developmental delays, like infants born at preterm.[17] Prone lying is often reported to be the "least favorite" play position of infants born at preterm placing them at higher risk of developmental delays and positional plagiocephaly.[17–19] Infants at risk of developmental delays perform poorly in prone skills compared to motor skills in a supine position.[19,22-23] Current education programs and "tummy time toys" do not address the need for an easily implemented prone play strategy for parents or daycare centers. There is need for an evidence-based intervention that can be used by physical therapists, early intervention providers, parents and daycare centers to increase tolerance for prone play and improve prone motor skills.

The intervention evaluated in this feasibility study utilizes technology to enhance infant's poor tolerance and prone motor skills using 2 key principles: (1) Positive reinforcement; and (2) the "Just Right" Challenge. The principle of positive reinforcement is derived from Operant conditioning (OC) which is a form of associative learning. OC proposes that a certain behavior can be encouraged by associating it with positive reinforcement.[22] OC techniques have been used with interventions to enhance sucking, vocalization, smiling, head turning, and reaching in infants.[23–25] For instance, by using a pacifier that plays mother's voice when sucked at a certain pressure, physical therapists and nurses in the NICU were able to encourage sucking and improve feeding outcomes in infants born preterm and facilitate early discharge.[26,27] In another study, toys that moved and made sound only upon contacts encouraged 2.9 months old infants to contact more and practice reaching and object exploration.[28] Our novel intervention harnesses the benefits of OC to encourage motor behaviors in prone. The Prone Play Activity Center

(PPAC) is rehabilitation device developed by the research team to provide positive reinforcement in the form of a toy activation in response to a head lift and will be used to implement the proposed intervention. The second principle of the intervention is the utilization of the “Just Right Challenge” which refers to the need for challenging the infant to work towards a goal just beyond their currently ability. Constraint induced movement therapy (CIMT) and bi-manual therapy are examples of proven, evidence based interventions utilizing the principles of motor learning.[29,30] Shaping is one of the principles of CIMT that emphasizes increasing the difficulty level of the training as the performance improves for maximum functional gains.[31,32] Consistent with motor learning theory and shaping, the “Just Right” challenge allows for regular success and feedback on meeting an intermediary goal while working towards an ultimate goal. Using a variable threshold on the PPAC the “Just Right” Challenge threshold can be adjusted daily by parents to ensure ongoing positive reinforcement and challenge.

The purpose of this study was to conduct a pilot trial to assess the feasibility of two home based interventions (one high-tech and one low-tech) using positive reinforcement strategies to improve tolerance for prone positioning and positively impact motor development in 3-6 months old infants. Specifically, the aims of this feasibility trial were to determine the feasibility of delivering the proposed interventions and evaluate if the proposed outcome measures are able to detect change in motor skills and prone tolerance in infants. The study also which factor(s), in addition to the key elements of the interventions, may influence prone motor skills during the intervention period and as such need to be considered as potential mechanisms of action in future efficacy studies.

Methods

Participants and setting. A convenience sample of 10, 3 to 6 months old infants born at term (50% female; mean age = 4.19 months, SD = 0.7 months) were recruited. Infants were identified from the community and parents provided informed consent for all infants. The university's institutional board approved the study. Infants who participated in this study received an age-appropriate infant toy at the end of the study. Infants were recruited from September 2017 – February 2018.

Full term infants with poor prone motor skills and poor prone tolerance were eligible for the study. Poor prone motor skills were defined as a score of 2 to 6 in the prone subsection of Alberta Infant Motor Scale (AIMS). Poor prone tolerance was identified as fussing/crying for more than 30 seconds during a five minute period in prone, and validated by parents' statement that the infant did not enjoy prone play. Fussing and crying was defined using the descriptors from Brazelton infant behavioral state (state 6).[33,34] Infants born with brain injury or any neurological event associated with a risk of neurodevelopmental disabilities, musculoskeletal deformity, genetic syndromes, visual and hearing problems, or any other disorders or medical complications limiting participation in assessments and intervention were excluded from the study.

All infants enrolled in the study participated in the same assessment schedule, regardless of group assignment. Post baseline assessment and collection of demographics and socio-economic status information, infants were randomized to the High-technology group (HTG) or the Low-technology group (LTG). All assessment sessions were conducted either in the infant's home or at the Motor Development Lab at Virginia Commonwealth University based on parent's choice. Visits were scheduled during a time of the day when a parent indicated that the infant was usually awake and playful

Intervention

The high-technology intervention. Infants in the HTG participated in a 3 week, home-based intervention program led by parents to improve their infant's prone tolerance and promote motor development (Figure 3). The active ingredients of the intervention are to 1) positively reinforce infant's initial efforts to lift their head in prone and to 2) progress the intervention to provide the "just right" challenge for prone play daily. The active ingredients were administered by the use of the Prone Play Activity Center (PPAC) (Figure 4) in the infant's play routine. The PPAC is a rehabilitation device developed by the investigators and that has the following components: 1) ultrasonic sensors 2) Arduino Uno microcontroller 3) dancing/singing toy. The sensors locate the position of the infant's head in space and records distance from the infant's head to the floor. The microcontroller compares the infant's head height to preset settings and activates the toy if conditions are met. For example, if the microcontroller is set to activate the toy when the infant's head is ≥ 10 cm off the floor the toy will turn on when the head is ≥10 cm and turns off when the infant lowers his head to < 10 cm. On day 1 of the intervention, the researcher educated the parent on the importance of prone play with the use of "Back to sleep, Tummy to Play" brochure from AAP.[35] This was followed by a demonstration of the features and functions of PPAC. The researcher coached the parents to set the PPAC to elicit toy activation at their infant's "just right" challenge of prone play. Parents were oriented to the intervention model so they understood when their infant lifts his/her head to the established threshold, the toy would activate and sing and dance until the infant's head drops below the threshold. A four step coaching model was used to support parent's ability to understand the concept of "just right" challenge of prone play: Step 1: Researcher determined the 3 "just right" challenge levels of prone play (easy, moderate and challenging) using infant's average head lift height (AHH) calculated on the first day of intervention. Based on our pilot data, the average height was used to calculate the “just right” prone play activity levels: a) “Easy” level – threshold height is set at 25 % below the day 1 average head lift height b) “Moderate” - threshold height equals the day 1 average head lift c) “Challenging” level- threshold height is 25% above the day 1 average head lift height. Step 2: Researcher wrote down the easy, moderate and challenging threshold heights in an intervention manual for parents to refer to during the intervention period. All parents were asked to begin the intervention using the “Easy” prone play activity level. This approach facilitated infant’s first experiences using the PPAC and allowed them the opportunity to activate the toy multiple times, to learn the association between their head movement and toy activation. The moderate and challenging levels were used to continue to positively reinforce the head lift as the infant improved their ability to raise the head and as tolerance prone lying improved. Step 3: Parents were asked to administer at least 30 minutes of prone play with PPAC over 15 days 3 week time period. Parents had 24 hour access to the PPAC in the home and could pace the intervention in 4 to 5 short periods (6-8 minutes) to avoid fatigue and gradually increase the duration based on their infant’s behavioral state. Step 4: Parents were coached to advance to the next “just right” challenge level of prone play when their infant’s performance met the increment criteria. The increment criterion was “the infant is able to complete at least 30 minutes of prone play in the PPAC during a 24 hour period without crying and activating the toy at least once”. If the parent perceived their infant met the criterion they advance to the next level (moderate or challenging) based on the threshold levels provided by the interventionist at the first visit. Along with the PPAC, parents received an intervention manual and an activity log, both paper and electronic versions. The manual included an orientation to the PPAC and how to adjust the “just right “challenge prone play level. The manual also included the infant’s individually determined “Just Right” Challenge thresholds so the parent could adjust the threshold knob as directed. The activity log was designed to capture the number of times per day and total time the infant played in prone. The interventionist conducted an in-person session with a parent of each child on Day 7 and Day 14 of the intervention period to discuss any issues with PPAC, talk about the intervention key ingredients and ask parents to demonstrate the intervention and how they determined the "just right challenge" level for that day's session.

The low technology intervention. Parents of infants in the EG received the same "Back to sleep, Tummy to Play" brochure as the HTG. Parents were asked to incorporate at least 30 minutes of prone play in their infant's daily routine, 15 days over 3 weeks. Parents were advised to pace the intervention in 4 to 5 short periods (6-8 minutes) to avoid fatigue and gradually increase the duration based on their infant's behavioral state. Using the brochure as a guide, parents were provided with tips to encourage prone play including by placing themselves or toys in front of the infant or holding the infant on their chest and talking to the infant. Use a towel roll or u-shaped pillow under the infant' chest was described and demonstrated by the researcher. On day 1 of the intervention, parents received an intervention manual outlining the goal of 30 minutes of prone per day and an activity log with the same questions as the HTG to document time in prone. An investigator met with the parent on Day 7 and Day 14 of the intervention period to discuss their infant's prone play routine and any issues encountered in administering prone play or completing the activity log, thus matching the frequency of researcher parent contacts between groups.

Assessments. To assess feasibility of completing a clinical trial of the proposed High technology intervention to advance prone motor skills, we evaluated enrollment and outcome assessment completion statistics. To estimate the enrollment and retention rate, the number of parents who expressed interest in the study through a phone call or email to the research team, number screened for eligibility, enrolled, and retained were tracked.

Adherence of parents and the interventionist to the HTG and EG interventions was evaluated by tracking the frequency of intervention visits completed and key intervention principles administered by the interventionist and parents. After 7-day and 14-day intervention visit for both groups, the interventionist recorded the principles utilized during the session to self-assess her adherence to the intervention procedures. To describe differences in the HTG and EG, information from the activity log was used to document the number of session parents used the PPAC (HTG only), amount of time per day infants' spent in prone, and amount of time per day the parent-infant dyad spent in face to face interaction in prone. A video of the Day 7 and Day 14 intervention session was used to evaluate parents' adherence to the interventions. Videos were scored by the interventionist using a similar intervention principles checklist used to score interventionist's adherence. These values were compared with the anticipated feasibility thresholds (Data analysis section) to determine parent's adherence in both the interventions.

For the identification of change in infants' tolerance to prone lying, we developed a measure of Prone Tolerance. Infants were placed in prone lying by the researcher for a maximum 15 minutes to assess prone tolerance. The testing began as soon as the examiners hands left the infants body and ended after 15 minutes or stopped any time the infant cried for more than 30 seconds. Crying was defined using the descriptors from Brazelton infant behavioral state (State 6).[33,34] The time lapse between the start and end of the trial was calculated as a measure of the infant's tolerance towards prone position. The score ranges from 0.5-15 minutes, where a score of 0.5 represents that the infant cried for 30 seconds immediately after being placed in prone position and a score of 15 represents the infant did not cry for more than 30 seconds during the 15 minutes of testing. The Smallest Detectable Change (SDC) calculated for this measure is 4.6 minutes calculates using the standard error of measurement of prone tolerance scores of infants in this feasibility study. This measure has not been validated yet.

Outcome measures. AIMS and Gross Motor Function Measure (GMFM) – 88 were completed at baseline and end of the intervention (EOI) period (Day 0 and Day 22). These measures were assessed for feasibility and sensitivity to determine which will be used in future studies. While the measures were administered by the same person who completed the intervention (Ms. Tripathi) a blinded, and reliable assessor scored the video tapes of the assessments. The AIMS is a reliable and valid observational assessment scale used to measure gross motor abilities in infants from birth through independent walking.[36,37] It consists of 58 items organized into four positions: 21 prone items, 9 supine items, 12 sitting items and 16 standing items. Each item is scored as either “observed” or “not observed”. The “least mature” and “most mature” item observed is marked for each of the four position. The items observed between the least mature and most mature item in a position represents the “window” of current skills for that position. The AIMS raw score for each position is the credit infant receives for sum of all the items before the window and for each items observed with in the window. The sum of the raw score in each position is the total AIMS score. AIMS evaluates three aspects of motor performance- weight-bearing, posture and anti-gravity movements. It can be completed within 15-30 minutes. The Smallest Detectable Change (SDC) for AIMS is 3.88 raw score points.[38] The GMFM-88 is a valid and reliable clinical measure designed to evaluate changes in gross motor function in children of 0-5 years of age with cerebral palsy (CP).[39] While the validity and reliability of GMFM has been evaluated for children with CP and Down syndrome, we decided to use it for typically developing children as: 1) GMFM - 88 does a detailed sampling of motor skills that are “typical” of normal development and 2) in our future studies we may include children who are at high risk of cerebral palsy, making it an appropriate measure for this feasibility trial. GMFM- 88 consists of 88 items under 5 dimensions: Lying and Rolling, Sitting, Crawling & Kneeling, Standing and Walking, Running and Jumping. It uses a 4 point scoring system to score each item on the scale of 0- 3 where (0 = does not initiates, 1= initiates, 2 = partially completes and 3 = completes). The sum of the score on each item is the total GMFM score and represents the percent of the test items the child could complete. The SDC for GMFM-88 is 3.02 points in children with a mean age of 3.7 years.[40] Percentage of infants who reached SDC was calculated to compare the sensitivity of the AIMS and GMFM-88.[41]A standardized set of toys were used for both AIMS and GMFM to motivate infants to demonstrate a particular skill, if the skill was not observed during free play.

Implementation of the intervention. To document that parents were completing the intervention as planned during the non-supervised sessions, it was important to determine how much time the infants spent in prone each day. Parents selected one of the following options on the activity log to report the amount of time the infant was in prone every day: < 15 minutes, 15 – 30 minutes and > 30 minutes of prone time. This information was used to determine the percent of days the total sample practiced prone for <15 minutes, 15 to 30 minutes or greater than 30 minutes out of the total expected parent reports (5 reports per week for each participant; for HTG (4 x 5) 20 and for EG (5 x 5) 25 total parent reports). If the log was not completed or no record of time spent in prone was made in the activity log, no prone time was assumed for that day and a duration of 0 was included in calculations for that day. To determine if infants in the HTG progressed through the “Just right” levels of prone play, each week’s prone play level (easy, moderate and challenging) was tracked using the activity log and parent reports during the weekly visits.

Data analysis. Descriptive statistics were used to describe the study sample and feasibility thresholds were determined apriori. We consider enrollment and retention feasible if 75% of the eligible infants are enrolled and 90% are retained. The intervention was considered feasible if the interventionist reviews 90% of the key principles of the intervention with the parents, parent completes 30 minutes of prone play on at least 85% of planned session (in the PPAC for the HTG), and parents correctly sets the “Just Right” level of prone play 100% of the time. We considered the prone tolerance measure to be feasible if more than 90% of the time the infants completed the measure without achieving the lowest or highest score. To determine if AIMS and GMFM- 88 are sensitive to change over time, we compared the percent of infants from the total sample whose change on the AIMS and GMFM- 88 from baseline to end of intervention reached the SDC. In addition, to evaluate if AIMS and GMFM-88 are sensitive to detect differences in the HTG and EG we calculated the percent of infants in each group who improved more than the SDC on each measure. The measure with the greater sensitivity to detect group difference will be used in future studies. We also calculated Cohen’s d effect sizes with 95 % confidence interval (CI) for the total sample and on the group differences in the AIMS, GMFM-88, and prone tolerance changes scores from baseline to end of intervention for use in planning for the future studies. Consistent with the CONSORT guidelines [42] a formal sample size calculation was not performed for this feasibility study but the results of this study will allow for sample size calculations in future studies.

Given the nature of this study as a feasibility trial the individual infant’s age, AIMS, GMFM – 88 and prone tolerance scores at baseline, weekly progression of the duration of prone play, change in the AIMS, GMFM-88 and prone tolerance scores at the end of the study are evaluated descriptively (Table 3).

Results

Of the infants screened for eligibility, 76 % infants were eligible for participation. The 24% not eligible were either not in the age range or had prone motor skills and prone tolerance above the required range for inclusion. All infants who met the eligibility criteria consented to participate in the study and completed the baseline testing, resulting in a sample of 10 infants, 5 in each group. Infant characteristics are shown in Table 1. All 5 infants in the EG completed the study. Of the 5 infants in the HTG, one infant was lost to follow up after baseline testing. The parent of the infant who was lost to follow-up shared the concern of not being able to use the PPAC due to sibling interference.

Parent and interventionist adherence. The interventionist completed 95% of the total required intervention session with 100% adherence to the key principles. One session was missed due to one infant dropping out of the study after the baseline visit.

High technology group. Of the anticipated 15 days of parent reported intervention, 96 % of the time parents reported information on prone play in the activity log. One parent did not complete the log after a week the infant spent most of the days in a daycare facility. Parents of infants in the HTG reported using the PPAC on 93 % of the 15 anticipated intervention days. Only 30 % of the 15 anticipated sessions, parents in the HTG group used the PPAC for > 30 minutes per day during the study. The average duration of PPAC used per day was 18(7) minutes as reported by parents in the activity log (Table 2). Of the planned 15 sessions of prone play, 93 % of the time infants practiced prone play. Parents reported their infant practiced 15 – 30 minutes and > 30 minutes of prone play 27 % and 47 % of the time respectively (Table 3, Figure 5). Parents in the HTG identifying the "Just Right" level of prone play 100% of the time when asked the weekly visits (Table 2). However, 75 % of parents progressed their infant to a higher level than the one recommended. These parents reported that the suggested level was too easy for their infant. Parents often reported that completing 30 minutes in any prone play level is challenging due to infants' poor tolerance after a certain period. They would increase the difficulty level to provide the infant with an opportunity to practice pushing up their upper body to a higher level until the infant fatigued and became intolerant of prone.

Education group. Of the anticipated 15 days of parent reports, 69 % of the time parents reported information on prone play in the activity log. Fifty three percent of the eligible days, parents reported that their infants practiced prone play. On 46 % of the reported days the infant practiced prone play for 15 – 30 minutes and only 4 % of the time for at least 30 minutes per day (Table 3, Figure 5).

Prone tolerance and motor development. The prone tolerance measure developed for this study is a feasible measure. A high percent of infants (95 %) completed the prone tolerance measure without achieving the lowest (0.5 minutes) or highest (15 minutes) score on the measure.

Sensitivity of outcome measures to change over time. Eighty eight % (total sample 8 of 9) of infants had a positive change in their prone tolerance score, 66 % of infants had a change in prone tolerance scores greater than SDC. While 100 % and 88 % (total sample 8 of 9) of infants had a positive change in their GMFM-88 and AIMS score respectively, only 44% (total sample 4 of 9) of infants had a change in the AIMS more than its SDC and 78 % (total sample 4 of 9) had a change more than the GMFM-88's SDC. A Cohen's d of 1.91, 95% CI (0.72 – 2.92) for prone tolerance score, 1.31, 95% CI (0.24, 2.26) for GMFM- 88 score and 1.42, 95 % CI (0.39 – 2.46) for AIMS score was found for the total sample from baseline to end of intervention (Figure 6-8).

Sensitivity of measures to detect group differences. In order to measure the sensitivity of the outcome measures to different interventions we calculated group differences. This is not a measure of efficacy of the intervention. While prone tolerance increased in both groups, all infants in the HTG and 40% of infants in the EG had an increase in their prone tolerance scores greater than SDC (Figure 6, Table 4). In the HTG and EG, 100 % and 60 % of infants respectively had a change in their GMFM-88 score more than the SDC (Figure 7, Table 3). All infants in the HTG had a change in their AIMS score more than SDC; however, none of the infants in the EG had a change in their AIMS score that achieved the SDC. (Figure 8 and Table 3). A Cohen's d of 1.71, 95 % CI (0.03 – 3.01) for prone tolerance score, 0.98, 95% CI (-0.50, 2.25) for GMFM-88 score and 2.97, 95% CI (0.84 – 4.43) for AIMS score was found for the differences in the change scores between the groups.

Description of potential factors influencing prone play time in an infant's routine. There was a variability in the rate of progression in duration of prone play between and within groups. For example, infants 1, 2 and 3 appeared to make greater gains in all outcome measures than infant 4 in HTG (Table 3). However, infant 4 does not appear to have difference in the baseline scores and is of a similar age at baseline to those that improved the most. The only notable difference is that infant 4 did not progress in the time she spent in prone based on parent report as quickly as infants 2 and 3. Infant 9 in the EG had the lowest motor development scores at baseline and also made the least progress in the duration of prone play at home in the EG. However, infants with similar scores made improvements in the HTG. Thus, age does not appear to be related to outcome scores.

Discussion

Our feasibility trial suggests that the use of a high tech intervention to enhance prone tolerance and motor development is feasible for use in future studies. Families were eager to participate as reflected in the 100% enrollment and 90% retention rate. The only parent who opted out of participation from the HTG arm of the study conveyed the concern of not being able to use the PPAC due to sibling intrusion. The PPAC is a light weight device that is easy to carry and move but it can be time consuming for a parent to put all the components together. Considering this we advised parents to not to take it apart resulting in a challenge for this parent to keep a 2 year old away from the novel device. In future research this issue can be solved by creating an easy to collapse and mount iteration of the PPAC so parents can put away the device between play sessions. Future iteration of the PPAC should also include an automatic shut off to prevent batteries from running down when a parent forgets to turn off the device which occurred frequently.

Both interventions were feasible to teach parents with the interventionists covering all needed material at the sessions. While the interventions could be taught to parents, and the parents in the HTG clearly understood how to adjust the Just Right Challenges, there were some challenges in adhering to the recommended dose of the intervention. Parents of infants in both the groups demonstrated understanding of the intervention guidelines, however they had difficulty practicing at least 30 minutes of prone play (in PPAC for infants in the HTG) per day. A parent reported *"30 minutes a day is too much and difficult to achieve but… we are trying to get through it"*. A possible explanation for not being able to get through at least 30 minutes of prone play could be infants' poor tolerance to pronelying. The average tolerance of infants to prone position in the beginning of the study was 2.6 minutes for the HTG and 4.2 minutes for the ED. Expecting parents to implement at least 30 minutes of prone play per day in a group of infants with extremely low tolerance for prone might be impractical even when asked to spread the intervention out over multiple times per day. However, parents in both the groups incorporated prone play into their infant's routine during the study on almost all days they completed the log (93 % in HTG and 53 % in EG). The total time spent in prone each day increased in both groups. In future studies we will consider making a staged goal for increasing prone. For example 15 minutes in week 1, 20 minutes in week 2, 30 minutes in week 3. Thus parents would be encouraged to reach a target that was consistent with the infants improving prone tolerance. Parent's poor adherence to completing the activity log was a common finding among both the groups. Parents often reported that the activity log is too long and even with the electronic version they tend to miss the notification to complete the activity log on some days during the 3 week intervention period. Parents suggested adding a feature in the electronic version that allows them to track the number of times they filled the log and to fill out missed entries up to 24 hours later. In the future, the PPAC should also be modified to add a data storage unit that can be used to track the amount of time the PPAC was used and information on the activity of infants in the PPAC. To summarize our findings in terms of comparing it to the feasibility threshold set apriori, none of the parents of infants in HTG and EG met the threshold of providing at least 30 minutes of prone play time on 85 % of the days during the intervention period. The feasibility threshold of 100 % set at parents' ability to identify the "Just Right Challenge" correctly was achieved by parents in the HTG group. While 50% of the goals were achieved, we continue to believe the intervention is feasible with some modifications as suggested by participants.

Majority of infants in the study had a positive change in their AIMS and GMFM-66 scores. Each of these measures had the same number of infants from the total sample (4 out of 9) that had a change in their scores more than the SDC. This finding suggests that both measures were equally sensitive to change over time for the total sample from baseline to end of intervention. Although we found a large effect size for both the motor development and prone tolerance measures to change over time in the total sample, the lower bound of the CI for GMFM-66 overlapped zero which means that this measures may not be sensitive to change in a 3 week period. In terms of discussing our findings on the sensitivity of the measures to detect group differences, in the HTG, both the AIMS and GMFM- 66 exhibited change over time suggesting either measure was sensitive to change in this group. However, only GMFM-66 was sensitive to change over time in the infants in the EG, as no infant in the EG had an increase on the AIMS score more than the SDC. AIMS had a promising effect size and CI compared to GMFM-66. This reflects that the AIMS may be a more sensitive measure to detect group differences in response to the proposed intervention. However, the insensitivity of AIMS in detecting change in motor skill in EG over time as seen by GMFM-66 should not be ignored. Thus it continues to be unclear which measures, the AIMS or GMFM-66, is more sensitive to the changes that can be reported after a 3 week intervention.

The prone tolerance measure developed for this study is a feasible measure to administer; however, the ability of this measure to detect group differences in the change in prone tolerance needs to be investigated more due to the lower bound of CI approaching the value of zero, indicating no real change. An increases in prone tolerance appear to be seen in infants whose parents also reported an increase in prone play duration at home. The 2 infants (infant 2 and infant 3 in Table 3) with the greatest increase in prone tolerance also were reported to spend more than 30 minutes in prone at home more than any other infants and had an increase in the motor skills higher than the SDC on the GMFM-66. These findings, while preliminary, provide support for the use of this measure.

Our findings show preliminary support for the “active ingredients” of the HTG intervention administered using the PPAC. Of the 4 infants who completed the HTG intervention, the 2 infants who used the PPAC for the longest duration per day and reached the challenging level of the “Just Right Challenges” had the greatest positive, meaningful change in their motor development and prone tolerance (Table 2 and Table 3). As we explored the potential mediators, we did not see infant’s age, motor skills and prone tolerance at baseline modify the relationship between the intervention and infants’ motor skills and prone tolerance (Figure 3). However, infants who had a gradual increase in time spent in prone and practiced > 30 minutes of prone play at home had the maximum gain in prone tolerance and a real change seen in their motor skills (Table 3). While not conclusive given the feasibility status of this study, the preliminary findings support the theoretical model underpinning the intervention (Figure 3).

Future studies should continue to quantify the "Just Right Challenges" and the daily duration of PPAC utilization to measure the active ingredients in the HTG. In addition, inclusion of the daily duration of any prone play will allow for quantification of the changing prone opportunities and could serve as a mediators. It would be valuable to conduct a mediation analysis to confirm the mechanism of change and determine if changing prone opportunity, rather than the defined active ingredients, contributes to the change in motor skills.

Our research shares the goals discussed at Research Summit IV *"Innovations in Technology for Children with Brain Insults: Maximizing Outcomes*" by American Physical Therapy Association, of conducting innovative studies that collaborate with other disciplines such as biomedical engineers and use technology to promote structural and behavioral change in infants. By "hacking" a commercially available toy and using cost effective sensors to track movements we built a device that combines technology with the principles of associative learning. Using our knowledge of infant development and physical therapy intervention combined with this device we have developed a feasible intervention that shows promise for improving motor skills in early infancy. During this process we ensured that parents and infants can utilize the device in their natural environment to maximize the prospects of functional gains in infants.

Conclusion

Our study demonstrates the feasibility of the proposed high technology intervention. An efficacy clinical trial is needed to determine whether this novel intervention has the potential to influence prone tolerance and development in full term infants with poor prone tolerance and low prone motor skills as well as those at risk for developmental delays.

References

1. Back to Sleep, Tummy to Play. https://www.healthychildren.org/English/ages-stages/baby/sleep/Pages/Back-to-Sleep-Tummy-to-Play.aspx. Published 2017.

2. Tummy Time -AAP.org. https://www.aap.org/en-us/about-the-aap/aap-press-room/aap-press-room-media-center/Pages/Tummy-Time.aspx. Published 2018.

3. Dudek-Shriber L, Zelazny S. The effects of prone positioning on the quality and acquisition of developmental milestones in four-month-old infants. *Pediatr Phys Ther*. 2007;19(1):48-55. doi:10.1097/01.pep.0000234963.72945.b1

4. Klimo P, Lingo PR, Baird LC, et al. Congress of Neurological Surgeons Systematic Review and Evidence-Based Guideline on the Management of Patients With Positional Plagiocephaly. *Neurosurgery*. 2016;79(5):E627-E629. doi:10.1227/NEU.0000000000001428

5. van Vlimmeren LA, van der Graaf Y, Boere-Boonekamp MM, L'Hoir MP, Helders PJM, Engelbert RHH. Risk Factors for Deformational Plagiocephaly at Birth and at 7 Weeks of Age: A Prospective Cohort Study. *Pediatrics*. 2007;119(2):e408-e418. doi:10.1542/peds.2006-2012

6. Collett B, Breiger D, King D, Cunningham M, Speltz M. Neurodevelopmental implications of "deformational" plagiocephaly. *J Dev Behav Pediatr*. 2005;26(5):379-389. doi:10.1097/00004703-200510000-00008

7. Zachry AH, Kitzmann KM. Caregiver awareness of prone play pecommendations. *Am J Occup Ther*. 2011;65(1):101-105. doi:10.5014/ajot.2011.09100

8. Hunter JG, Malloy MH. Effect of sleep and play positions on infant development: Reconciling developmental concerns with SIDS prevention. *Newborn Infant Nurs Rev*. 2002;2(1):9-16. doi:10.1053/nbin.2002.31484

9. Shumway-Cook, A., & Woollacott MH. Motor control : Translating research into clinical practice. In: *Motor Control : Translating Research into Clinical Practice*. 3rd ed. Philadelphia: Lippincott Williams & Wilkins.; 2007:30-31.

10. Guidetti J, Wells J, Worsdall A, Metz AE. The Effect of Positional Support on Tolerance of Wakeful Prone in Infants. *Phys Occup Ther Pediatr*. 2017;37(3):308-321. doi:10.1080/01942638.2016.1185506

11. Guidetti JM. The effectiveness of infant positioning equipment on time spent in wakeful prone. 2011:40. http://utdr.utoledo.edu/graduate-projects.

12. Koren A, Reece SM, Kahn-D'angelo L, Medeiros D. Parental Information and Behaviors and Provider Practices Related to Tummy Time and Back to Sleep. *J Pediatr Heal Care*. 2010;24(4):222-230. doi:10.1016/j.pedhc.2009.05.002

13. Abbott A, Bartlett D. Infant motor development and equipment use in the home. *Child Care Health Dev*. 2001;27(3):295-306. doi:10.1046/j.1365-2214.2001.00186.x

14. Pin T, Eldridge B, Galea MP. A review of the effects of sleep position , play position , and equipment use on motor development in infants. *Dev Med Chil Neurol*. 2007;49:858-867.

15. Crouchman M. THE EFFECTS OF BABYWALKERS ON EARLY LOCOMOTOR DEVELOPMENT. *Dev Med Child Neurol*. 28(6):757-761. doi:10.1111/j.1469-8749.1986.tb03929.x

16. Gardner FE, Warren S, Weeks G V., Bennett R. Locomotor milestones and babywalkers. *Bmj*. 2002;325(7365):657. doi:10.1136/bmj.325.7365.657/a

17. Bartlett DJ, Fanning JEK. Relationships of equipment use and play positions to motor development at eight months corrected age of infants born preterm. *Pediatr Phys Ther*. 2003;15(1):8-15. doi:10.1097/01.PEP.0000051693.49199.41

18. Mawji A, Vollman AR, Hatfield J, McNeil DA, Sauve R. The Incidence of Positional Plagiocephaly: A Cohort Study. *Pediatrics*. 2013;132(2):298-304. doi:10.1542/peds.2012-3438

19. Mawji A, Robinson Vollman A, Fung T, Hatfield J, McNeil DA, Sauvé R. Risk factors for positional plagiocephaly and appropriate time frames for prevention messaging. *Paediatr Child Heal*. 2014;19(8):423-427. doi:10.1093/pch/19.8.423

20. Ratliff-Schaub K, Hunt CE, Crowell D, et al. Relationship between infant sleep position and motor development in preterm infants. *J Dev Behav Pediatr*. 2001;22(5):293-299. doi:10.1097/00004703-200110000-00003

21. Fetters L, Huang HH. Motor development and sleep,play, and feeding positions in very low birth weight infants with white matter disease. *Dev Med Child Neurol*. 2007;49(11):807-813.

22. Enright MK, Rovee-Collier CK, Fagen JW, Caniglia K. The effects of distributed training on retention of operant conditioning in human infants. *J Exp Child Psychol*. 1983;36(2):209-225.

23. Gerhardstein P, Kraebel K, Tse J. Using operant techniques with humans infants. *Behav Anal Today*. 2006;7(1):56-70. http://www.biomedsearch.com/article/Using-operant-techniques-with-humans/170113005.html.

24. Thelen E. Motor development: A new synthesis. *Am Psychol*. 1995;50(2):79-95. doi:10.1037/0003-066X.50.2.79

25. Dunst CJ, Trivette CM, Raab M, Masiello TL. Early Child Contingency Learning and Detection: Research Evidence and Implications for Practice. *Exceptionality*. 2008;16(1):4-17. doi:10.1080/09362830701796743

26. Standley JM. The effect of music-reinforced nonnutritive sucking on feeding rate of premature infants. *J Pediatr Nurs*. 2003;18(3):169-173. doi:10.1053/jpdn.2003.34

27. Chorna OD, Slaughter JC, Wang L, Stark AR, Maitre NL. A Pacifier-Activated Music Player With Mother's Voice Improves Oral Feeding in Preterm Infants. *Pediatrics*. 2014;133(3):462-468. doi:10.1542/peds.2013-2547

28. Williams JL, Corbetta D. Assessing the impact of movement consequences on the development of early reaching in infancy. *Front Psychol*. 2016;7(APR):1-15. doi:10.3389/fpsyg.2016.00587

29. Morgan C, Darrah J, Gordon AM, et al. Effectiveness of motor interventions in infants with cerebral palsy: a systematic review. *Dev Med Child Neurol*. 2016;58(9):900-909. doi:10.1111/dmcn.13105

30. novak I, Mcintyre S, Morgan C, et al. A systematic review of interventions for children with cerebral palsy: State of the evidence. *Dev Med Child Neurol*. 2013;55(10):885-910. doi:10.1111/dmcn.12246

31. Taub E, Crago JE, Uswatte G. Constraint-induced movement therapy: a new approach to treatment in physical rehabilitation. *Rehabil Psychol*. 1998;43(2):152-170. doi:10.1037/0090-5550.43.2.152

32. DeLuca SC, Landesman Ramey S, Rebekah Trucks M, Ainsworth Wallace D, Director I. Multiple Treatments of Pediatric Constraint-Induced Movement Therapy (pCIMT): A Clinical Cohort Study MeSH TERMS cerebral palsy combined modality therapy paresis restraint, physical treatment outcome. 2015:1-9. doi:10.5014/ajot.2015.019323

33. Brazelton 1918- TB. *Neonatal Behavioral Assessment Scale*. 3rd ed. . (Nugent JK, ed.). London : [Cambridge?]: London : Mac Keith Press ; Cambridge? : Distributed by Cambridge University Press; 1995.

34. Education PN. Understanding the behavior of term infants. 2003:1-14.

35. Back To Sleep, Tummy To Play. 2008.

36. Darrah J, Bartlett D, Maguire TO, Avison WR, Lacaze-Masmonteil T. Have infant gross motor abilities changed in 20 years? A re-evaluation of the Alberta Infant Motor Scale normative values. *Dev Med Child Neurol*. 2014;56(9):877-881. doi:10.1111/dmcn.12452

37. Piper MC, Pinnell LE, Darrah J, et al. Linked references are available on JSTOR for this article : Construction and Validation of the Alberta Infant Motor Scale (AIMS). 2017;83(August 1992):2-7.

38. Boonzaaijer M, Van Dam E, Van Haastert IC, Nuysink J. Concurrent validity between live and home video observations using the Alberta infant motor scale. *Pediatr Phys Ther*. 2017;29(2):146-151. doi:10.1097/PEP.0000000000000363

39. *Gross Motor Function Measure (GMFM-66 & GMFM-88) User's Manual*. [3rd ed.]. London : [Cambridge]: Mac Keith ; Distributed by Cambridge University Press; 2002.

40. Wang HY, Yang YH. Evaluating the responsiveness of 2 versions of the gross motor function measure for children with cerebral palsy. *Arch Phys Med Rehabil*. 2006;87(1):51-56. doi:10.1016/j.apmr.2005.08.117

41. Schuck P, Zwingmann C. The "smallest real difference" as a measure of sensitivity to change: A critical analysis. *Int J Rehabil Res*. 2003;26(2):85-91. doi:10.1097/00004356-200306000-00002

Tables

Table 1: Participants demographics

	HTG	EG
Age m(SD)	3.24 (2.37) months	4.1 (0.49) months
Female	25 %	60 %
Not Hispanic or latino	75 %	100 %
White	100%	100 %
Primary caregiver age		
26-35 years	75 %	60 %
36-45 years	25 %	40 %
Primary caregiver education level		
Bachelor’s		80 %
Master’s	100 %	20 %
Primary caregiver employment status		
Keeping house	50%	40 %
Working full time	50 %	60 %

Abbreviations: HTG – High Technology group; EG – Education group

Table 2: High technology group intervention "active ingredients" descriptors

HTG	Average PPAC use (mins/day)			"Just Right" prone play level		
	Wk 1	Wk 2	Wk 3	Wk 1	Wk 2	Wk 3
Infant 1	11	NR	NR	Easy	Moderate	Moderate
Infant 2	13	17	25	Easy	Easy-Moderate	Moderate-Challenging
Infant 3	12	34	30	Easy	Easy-Moderate	Moderate-Challenging
Infant 4	16	16	17	Easy	Easy	Easy-moderate

NR = no report.

Table 3: Possible mediators leading to change in prone tolerance and motor development

Total Sample	Age	Baseline motor development and prone tolerance scores			Frequency of < 15 minutes, 15 - 30 minutes and > 30 minutes of prone play sessions per week				Change in AIMS raw score	Change in GMFM-88 raw	Change in prone tolerance score
High Tech group		AIMS score	GMFM-88 score	Prone tolerance score	Time spent in prone (in minutes)	Week 1	Week 2	Week 3			
Infant 1	3.46	13	27	2.5	< 15	----	----	----	6*	6*	11.1
					15 – 30	5	----	----			
					> 30-	----	----	----			
Infant 2	3.82	15	26	1.9	No	----	5	5	6*	17*	11.9
					< 15	1		1			
					15– 30	2	1	2			
					> 30-	1	4	2			
Infant 3	5.69	20	40	3.9	No	1	----	----	4*	16*	11.1
					< 15	----	----	----			
					15 - 30	1	----	----			
					> 30	2	5	5			
Infant 4	4.77	16	36	2.25	No	2	----	----	8*	5*	6.2
					< 15	2	2	2			
					15– 30	3	2	2			
					> 30	----	1	1			
					No	----	----	----			

Table 3 cont: Possible mediators leading to change in prone tolerance and motor development

Total Sample	Age	Baseline motor development and prone tolerance scores			Frequency of < 15 minutes, 15 - 30 minutes and > 30 minutes of prone play sessions per week				Change in AIMS raw score	Change in GMFM-66 raw score	Change in prone tolerance score (minutes)
Education group		AIMS score	GMFM-88 score	Prone tolerance score	Time spent in prone (in minutes)	Week 1	Week 2	Week 3			
Infant 5	4.32	18	37	5.9	< 15	1	2	2	3	3	1.8
					15– 30	3	2	2			
					> 30	----	1	1			
					No report	1	----	----			
Infant 6	3.46	16	34	2.5	< 15	4	3	2	2	0	6
					15– 30	----	----	2			
					> 30	----	----	----			
					No report	1	2	1			
Infant 7	4.33	17	27	2.8	< 15	1	----	----	3	11*	0.4
					15– 30	4	4	----			
					> 30	----	1	----			
					No report	----	----	5			
Infant 8	4	20	39	4.5	< 15	1	----	----	0	4*	10.2
					15– 30	1	4	----			
					> 30		1	----			
					No report	3	----	5			
Infant 9	3.93	14	30	5.5	< 15		1	----	2	10*	-1.1
					15– 30	1	3	3			
					> 30	----	----	----			
					No report	4	1	2			

Table 4: Descriptive statistics of motor development and prone tolerance outcome measures

	Total Sample (n=9)		High Technology Group (n =4)		Education Group (n =5)	
Outcome measure	Baseline	End of Intervention	Baseline	End of Intervention	Baseline	End of Intervention
AIMS raw score	16.5 (2.4)	20.3 (2.5)	16.3 (2.2)	22.3 (2.0)	14.2 (3.0)	15.8 (2.4)
GMFM – 88 total score	25.1 (2.7)	27.5 (3.4)	25.5 (2.02)	29.4 (3.67)	25.0 (2.02)	26.7 (1.85)
Prone tolerance (in minutes)	3.5 (1.0)	9.9 (4.5)	2.6 (0.9)	12.7 (2.9)	4.2(1.5)	7.7 (4.5)

Figures

Figure legends

Figure 1: Contributor(s) –lack of prone play.

Figure 2: Prone play using A) commercial play gym and B) towel roll and toys.

Figure 3: High technology group intervention- Mechanism of change Note: the yellow boxes represents the active ingredients of the intervention.

Figure 4: Prone play using Prone Play Activity Center

Note: The translucent triangle represents a not on scale area of the ultrasonic sensors, sensing the position of infant's head in space. The red line represents the height of the virtual threshold.

Figure 5: Group comparison of progression in prone play over 3 weeks of intervention.

Figure 6: Change in prone tolerance score from Baseline to End of intervention of the total sample.

Figure 7: Change in AIMS score from Baseline to End of intervention of the total sample.

Figure 8: Change in GMFM-88 score from Baseline to End of intervention of the total sample.

Figure 9: Change in Prone tolerance score from Baseline to End of intervention of infants in High tech and Education group.

Figure 10: Change in AIMS score from Baseline to End of intervention of infants in High tech and Education group.

Figure 11: Change in GMFM-88 score from Baseline to End of intervention of infants in High tech and Education group.

Figure 1: Contributor(s) –lack of prone play

A)

B)

Figure 2: Prone play using A) commercial play gym and B) towel roll and toys

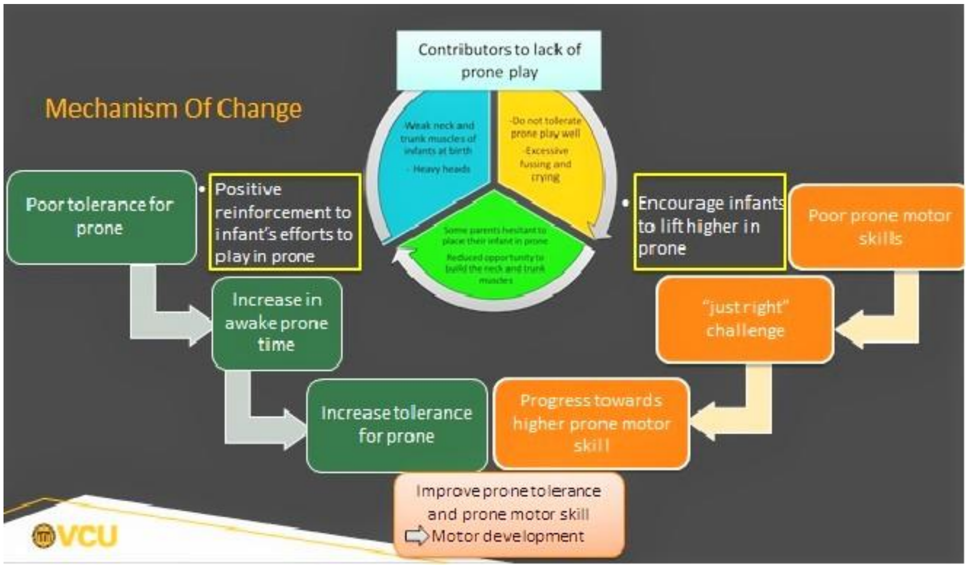
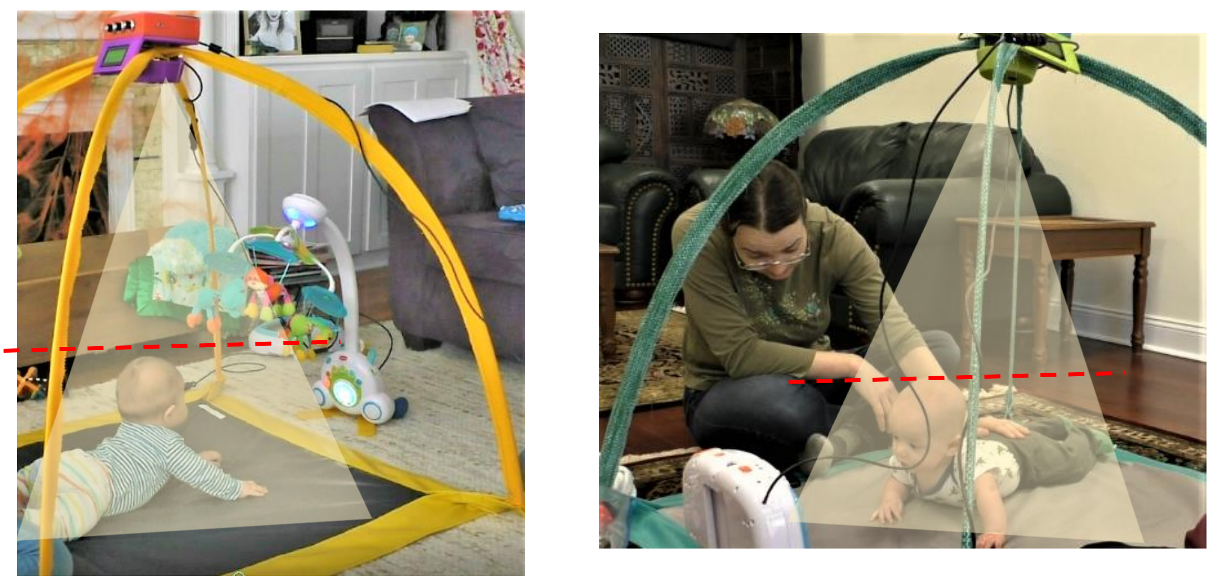


Figure 3 – High technology group intervention- Mechanism of change.

Note: the yellow boxes represents the active ingredients of the intervention



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Note: The translucent triangle represents a not on scale area of the ultrasonic sensors, sensing the position of infant's head in space. The red line represents the height of the virtual threshold.

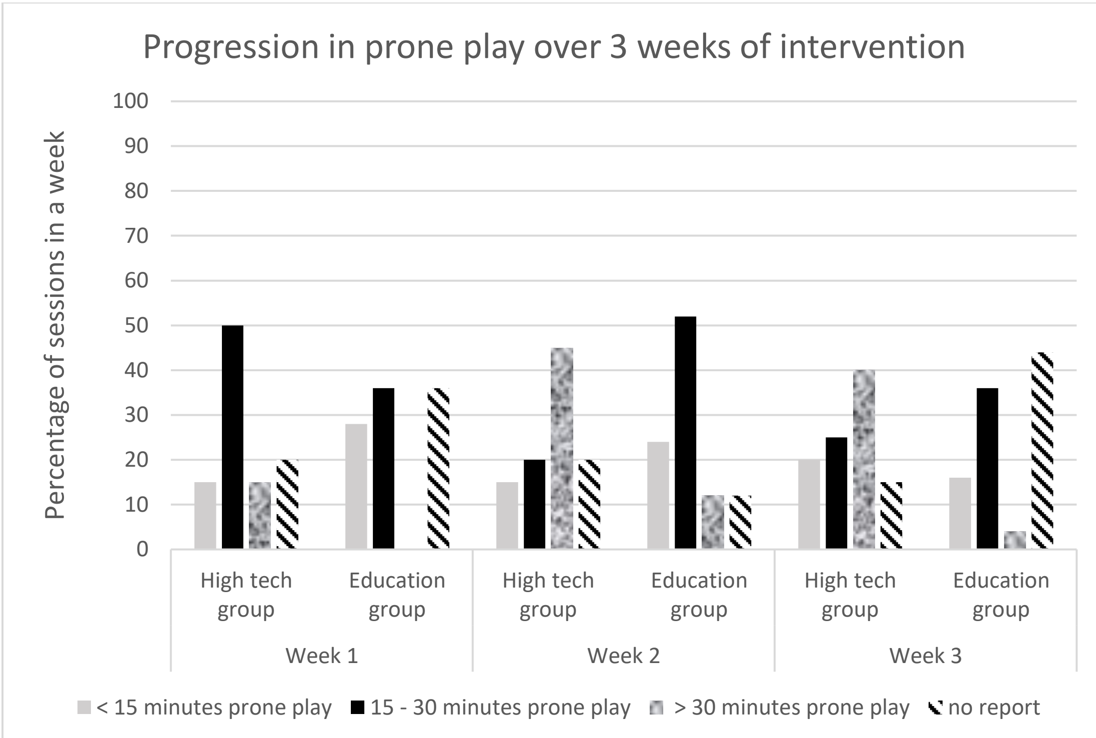

Figure 5: Group comparison of progression in prone play over 3 weeks of intervention.

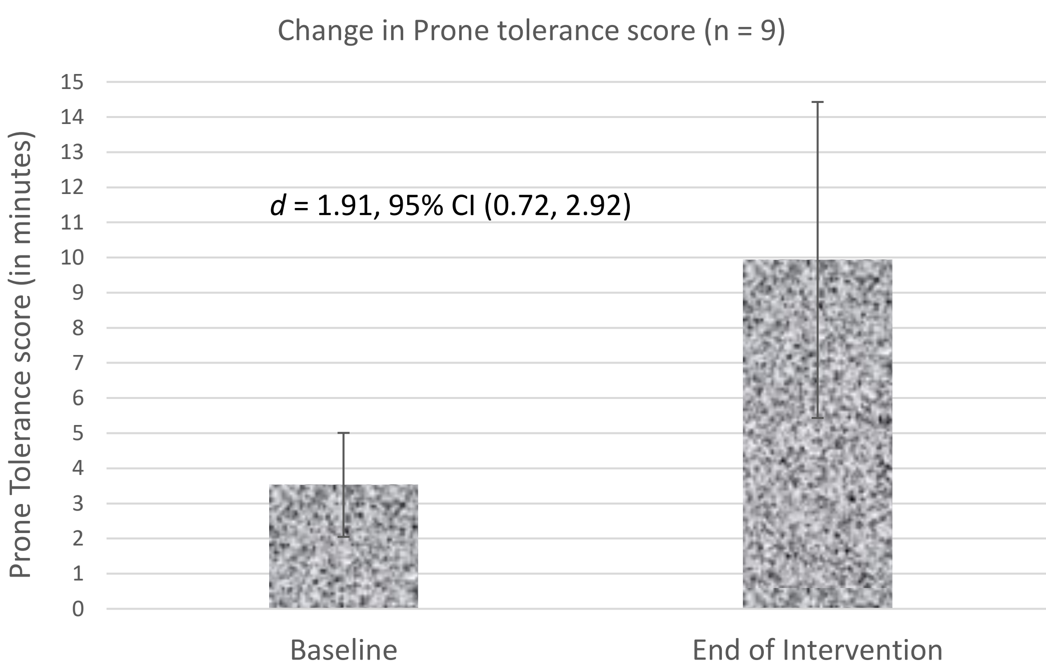

Figure 6: Change in prone tolerance score from Baseline to End of intervention of the total sample

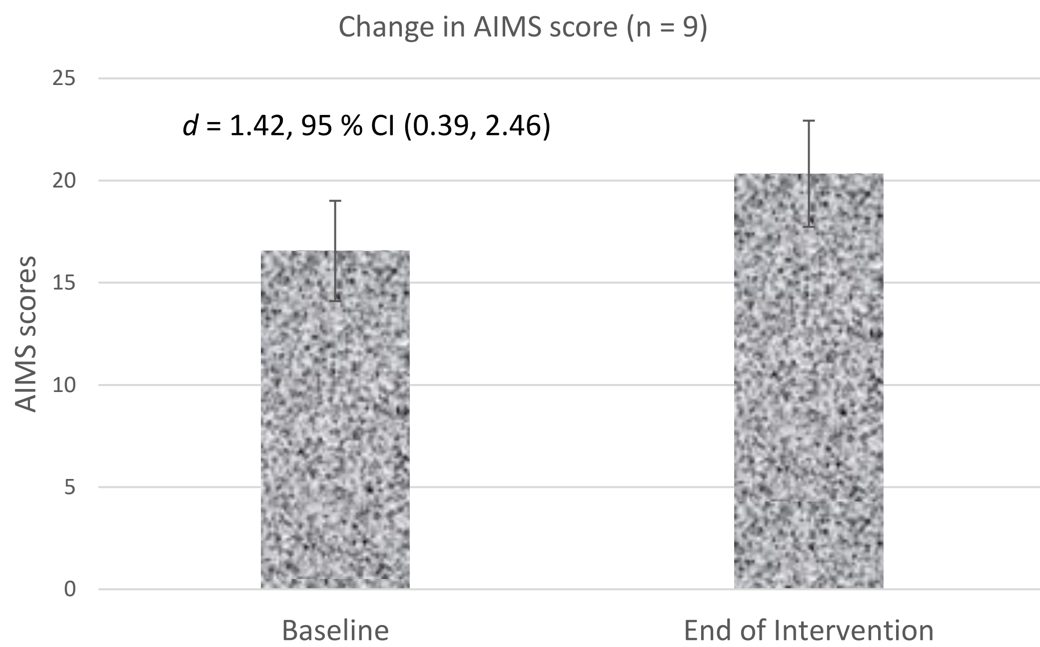

Figure 7: Change in AIMS score from Baseline to End of intervention of the total sample

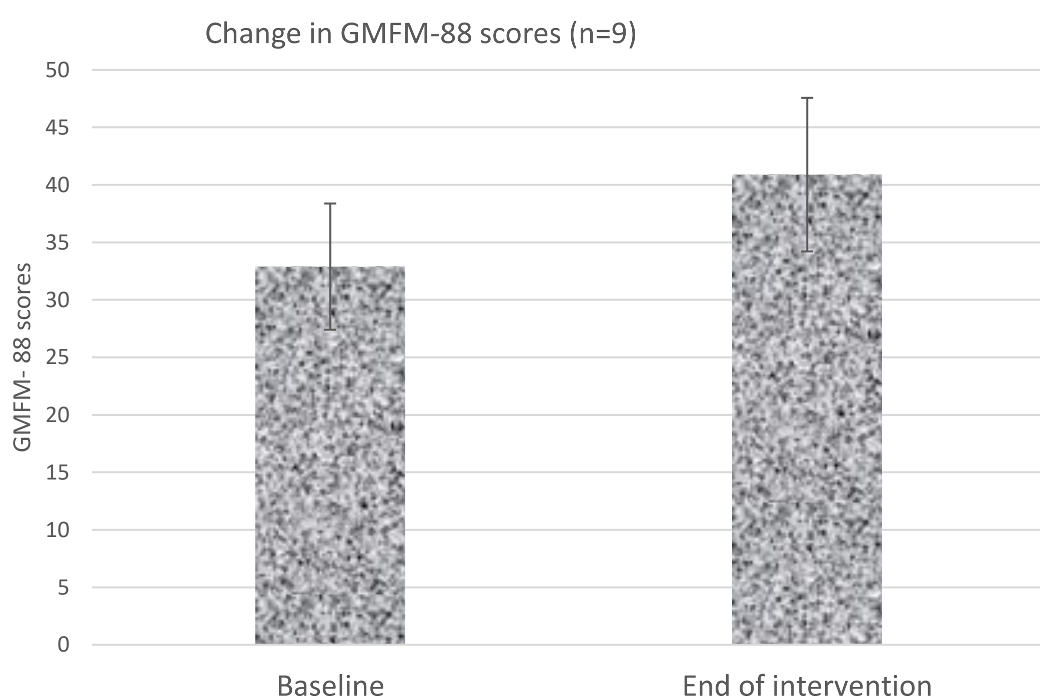

Figure 8: Change in GMFM-88 score from Baseline to End of intervention of the total sample

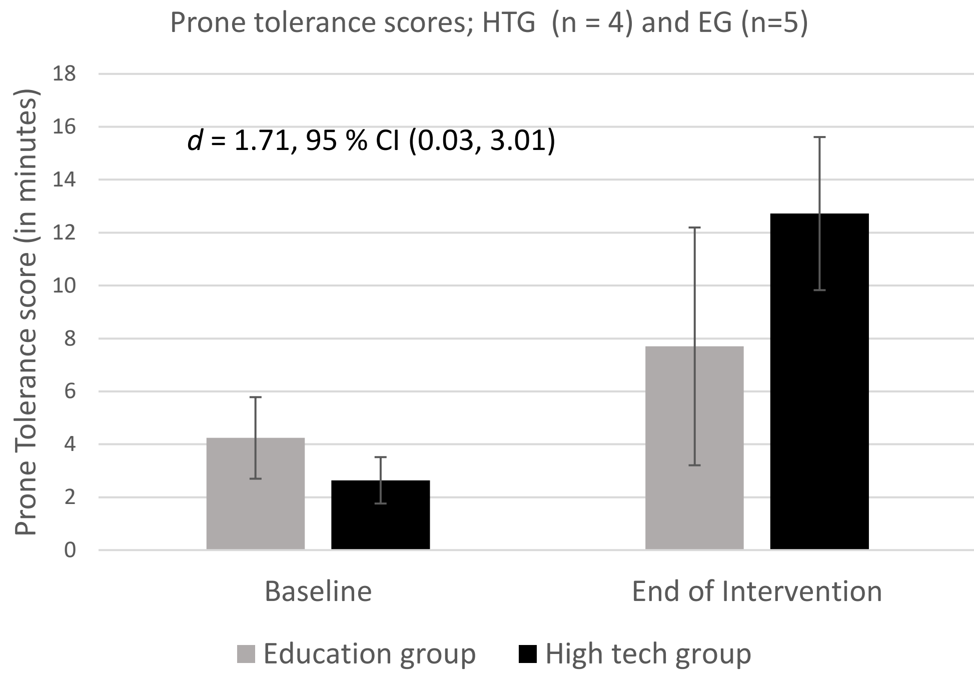

Figure 9: Change in Prone tolerance score from Baseline to End of intervention of infants in High tech and Education group.

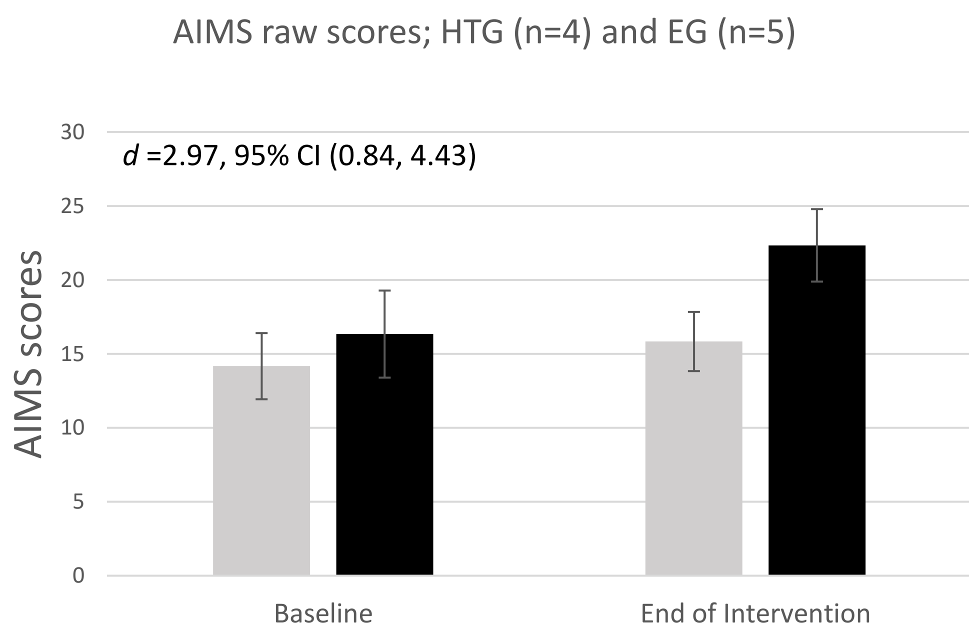

Figure 10: Change in AIMS score from Baseline to End of intervention of infants in High tech and Education group.

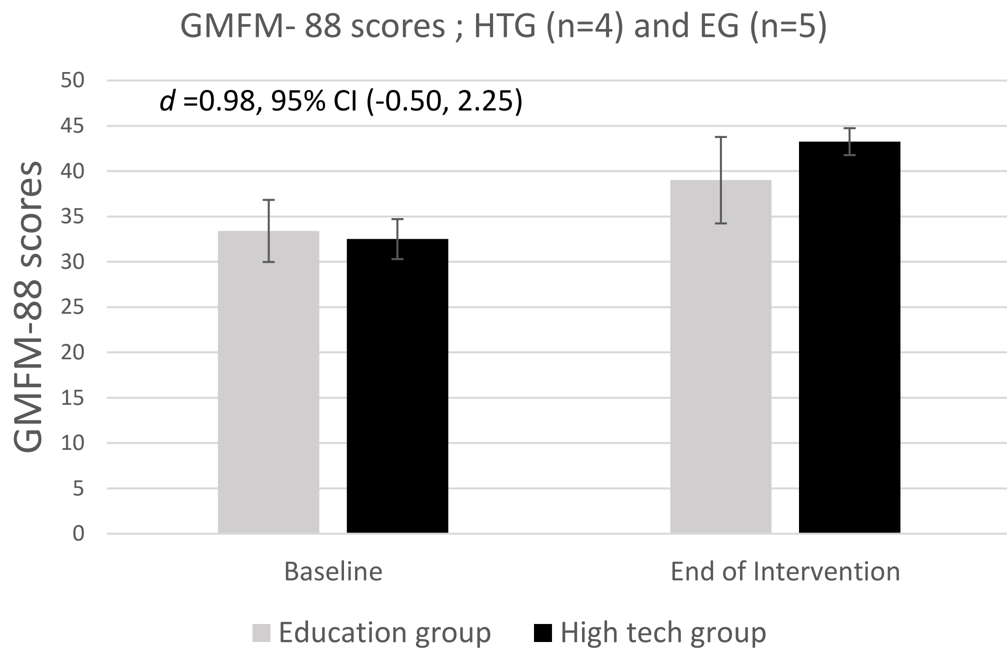

Figure 11: Change in GMFM-88 score from Baseline to End of intervention of infants in High tech and Education group.

Chapter: 4

A Motor Learning Paradigm Combining Technology and Associative Learning to Assess Prone Motor Learning in Infants

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Abstract

Background: Associative learning can be described as the ability to discover a causal relationship between two or more events. In this study we combined the principles of associative learning with technology to develop a paradigm to assess associative learning in prone. **Purpose:** This project is designed to understand if 3-6 months old infants can demonstrate 1) short term learning of an association between their upper body, head and torso movements and activation of a toy while in prone position and 2) retention of the association learned on day 1, 24 hours later. **Methods:** Twenty eight, 3 – 6 months old, typically developing infants were tested for 2 consecutive days on their ability to learn that lifting their head in prone would activate a toy. An instrumented play gym was used for 2 consecutive days using the same protocol on each day: 1) Baseline phase (2 minutes), toy won't activate in response to infant movement 2) Acquisition phase (8 minutes), toy activates for maximum of 10 seconds if the infant's head is above a threshold. Infants were categorized as 1) short term learners if the frequency of toy reactivations (FTR) or total duration toy was on (DTO) during Acquisition was 1.5 times Baseline and 2) retainers of the association learned on day 1, if FTR or DTO on day 2 was 1.5 times day 1's Baseline. **Results:** Of the 28 infants, data of 22 infants was included for analysis. Fourteen infants were categorized as short term learners on day 1. Of the short term learners on day 1, 3 infants demonstrated retention of the association. **Conclusion:** Our findings supports that when 3-6 months old infants born at full term are presented with a task of raising their head to a certain height to activate a toy, a majority of infants tend to learn the association of their movement with the activation of the toy.

Key words: Associative learning, Discovery learning, prone, motor learning

Introduction

During the first year of life, substantial changes are seen in the motor and cognitive skills of human infants.[1-3]Although the various motor and cognitive developmental milestones during infancy are well described in the literature, our understanding of the learning mechanisms underpinning their emergence is still evolving.

A contemporary view of infant/child development combines three constructs together: action, cognition and perception to understand how a child is learning a developmental skill. [2,3] Human movements are organized as actions that have a purpose and are guided by the knowledge or perception of the movement itself and the environment. For instance, Rovee-Collier[4] found that infants as young as 2 months of age can learn and remember to kick more with the leg that is tethered to an overhead mobile compared to the untethered one as the tethered leg can make the mobile move (mobile paradigm).[5,6] Infants' ability to learn the association between their leg movements and the mobile provided a premise for researchers to modify the original mobile paradigm and learn about the kinematics and motor control properties of infant's leg movements. The modern mobile paradigm developed by combining technology and the traditional mobile paradigm together is more challenging and complex where infants are required to kick above a virtual threshold in a specific movement pattern.[7,8] Some 3 – 4 months old infants have demonstrated the ability to change their kicking pattern and learn the association between the mobile and their kicks in the modified version of the mobile paradigm. Both traditional and modified mobile paradigm have been extended to assess learning and motor control abilities of infants with or at risk of developmental delays.[9–13] This line of research has served as a "proof of concept" for the current work. The present study is designed to understand if infants can learn an association between their upper body, head and torso movements and activation of a toy while pronelying.

According to operant conditioning (OC), a behavior can be encouraged or suppressed by associating it with a positive or negative consequence (rewards/punishments).[14] Operant conditioning is not a new practice. Operant conditioning techniques has been frequently used with sucking, vocalization, smiling, head turning, kicking and reaching as the target behaviors in infants.[15] For instance, by using a pacifier that plays mother's voice when sucked at a certain pressure, physical therapists and nurses in the NICU were able to improve feeding outcomes in infants born preterm and facilitate early discharge.[16,17] In another study, toys that moved and sounded only upon contacts encouraged 3 months old infants to contact more and practice reaching and object exploration.[18] Shaping, one of the basic component of constrained induced movement therapy, capitalizes on the use of operant conditioning in overcoming the "learned non-use" of the affected upper extremity in individuals with hemiparesis.[19] Through providing a series of rewards that provide positive reinforcement, therapist "shape" the upper limb movements required to successfully complete a task. Thus, operant conditioning seems to be a promising approach in encouraging motor behaviors.

In this study we have combined the principles of associative learning with technology to develop a learning paradigm that may be used to enhance prone motor control of infants. The American Academy of Pediatrics (AAP) through its "Back to Sleep and Prone to play" campaign emphasizes the importance of supervised awake prone play in an infant's routine to reduce the risk of developmental delays and positional head deformities.[20,21] Prone play is important for infants to develop strength and coordination in the neck, trunk and upper extremities muscles .[20] It provides natural opportunities for the acquisition of head control, reaching, sitting and prone mobility. Prone mobility is one of the early forms of locomotion in infants, expanding opportunities for them to explore and learn.[22] However, the dynamics of prone mobility are complex and requires a constant change and adaptations in infants' prone motor control.[22,23]

The associative learning paradigm developed for this study is designed to quantify if early in development infants have the ability to adapt their prone motor control to receive positive feedback.

At Research Summit IV "Innovations in Technology for Children with Brain Insults: Maximizing Outcomes" hosted by the Academy of Pediatric Physical Therapy of the APTA[24] , key research priorities. This research addressed two of these priorities: (1) what should be measured in children to capture slow, subtle changes in development; and (2) how technology can be made to adapt to a child's growth and changing abilities. The aim of our study was to determine if 3-6 months old infants can demonstrate operant conditioning by modifying their prone motor control and retaining this response 24 hours later. In order to demonstrate associative learning in prone, infants have to modify their existing prone control and adapt to the challenges of the associative learning model proposed in this study. We hypothesized that infants will demonstrate short term learning of the association in prone by using strategies to lift their head using move their upper body and torso to activate a toy 1.5 times more often in the acquisition phase compared to the same day's baseline phase. Second, we hypothesized that infants who learn the association on day 1 will retain the association learned 24 hours later at a significantly greater rate as compared to the non-learning subgroup.

Methods

This single group experimental design study included 28 typically developing infants born at term who participated in this study at 3-6 months of age. Schraber et al suggested that for a single group analysis, 10 participants per estimated parameter is accepted as there is no exact rule for the participants needed [25]. Using this information, we calculated our sample size to be 20 infants since we estimated to have 2 parameters: Frequency of Toy Reactivations (FTR) and

Duration of Toy On (DTO). With a conservative 30-40% of dropout rate we would need 8 more infants, so a total of 28 infants was determined as the ideal sample size of the study.

A convenience sample of infants from the community were recruited from May 2017 – February 2018. Infants were required to be born at full term (38-42 weeks of gestation) and to be able to lift their head well in prone, but not have the ability to crawl or creep. The prone motor skills criterion was established to ensure that infants had the motor abilities required to use the PPAC. In addition, infants were required to have prone tolerance (i.e., not fussing or crying greater than 30 seconds during the 5-minute period in prone while assessing the Alberta Infant Motor Scales -AIMS). This was added to the inclusion criteria to decrease the probability of infants dropping out of the study because the testing protocol was too challenging. Infants were excluded from the study if they were able to move out of prone or pivot, had a brain injury musculoskeletal deformity, genetic syndromes, visual and hearing problems, or other medical conditions limiting participation.

Procedure. All data collection sessions occurred either in the infants' home, the Motor Development Lab at VCU, or the infants daycare center during a time of day the caregiver reported the infant was typically awake and playful. After providing an IRB approved written informed consent for their infant's participation, parents were asked to fill out a form providing demographic for their child.

Associative learning paradigm in prone. Infants were assessed for associative learning and retention in prone using the Prone Play Activity Center (PPAC) (Figure 1). The PPAC is a high technology device that has the following components 1) ultrasonic sensors 2) Arduino Uno microcontroller 3) dancing/singing toy. The sensors locate the position of infant's head in space and records the head's distance from the floor. The microcontroller compares infants head height to its preset parameter or height of the threshold and activates the toy if conditions are met. For example, if the microcontroller is set to activate the toy when the infant's head is ≥ 10 cm off the floor the toy will turn on when the head is ≥10 cm and turns off when the infant lowers his head to < 10 cm. PPAC has two modes: 1) Continuous and 2) Interval mode. In the continuous mode the toy activates when the infant's head height matches with the preset parameters and will turn off only when the conditions are not met. In the interval mode, the same conditions must be met to turn the toy on, but the toy will turn off after a certain period of time or interval length even if the infant's head is above the threshold.

The associative learning testing protocol included two consecutive days of data collection. Day 1 consisted of the following: (1) Pre-Baseline phase (30 seconds); (2) Baseline phase (2 minutes); (3) Acquisition phase (AQ_1,2,3 and 4 each 2 minutes in length). Day 2 was identical with the exception of the pre-baseline phase being excluded from the protocol. Parents were asked to limit interactions with their infant during the testing to allow the infant to focus on the learning task. All parents were advised to be in view of the infant and smile if the infant gets fussy. If the infant continues to be distressed, parents were asked to say "I am right here, you are doing okay" in an encouraging tone. During the pre-baseline phase, infants were positioned in prone in the PPAC for 30 seconds. The position of an infant in the PPAC was standardized to ensure that the vertex of the infant's head was aligned at the center of the area covered by the PPAC sensors. A mirror toy was placed at the edge of the mat, in front of the infant for motivation. At the end of the 30 seconds, the PPAC calculated the Average head lift height (AHH). The AHH was used to set the Threshold head lift height (TH). TH is the height required by the infant to raise his/her head to activate the toy and was used for further testing. In the Baseline phase, infants were positioned in prone in the PPAC for 2 minutes. The PPAC toy did not activate in response to infants' movements in any way during this period. The purpose of the baseline phase was to provide us with information about the infants' head lift height when not in association with the activation of the PPAC toy. In the Acquisition phase, the PPAC toy was activated in response to infants' raising his/her head to a height equivalent or greater than the TH. The toy remained on for a maximum of 10 seconds or turned off anytime the infants' head was below the AT. We implemented "10 seconds rule" based on pilot work demonstrating that infants would hold their head up at or above the TH to keep the toy ON for the whole acquisition period and would not have the opportunity to explore the association between their movement and toy activation. The purpose of the acquisition phase determine the extent to which infants would demonstrate associative learning, allowing them the opportunity to learn the association through trial and error. Based on pilot testing, few infants could complete 8 consecutive minutes in prone without signs of distress. Therefore, at the end of the each 2 minute trial infants were rolled to a supine position for a 15 seconds break period. Data collection was paused any time during the testing an infant cried continuously for 30 seconds or more. Each phase was re-attempted once if paused due to behavioral state. Data of infants who did not complete the baseline and first three acquisition trials on either day was excluded from the analysis.

Data processing. A laptop was connected to the PPAC to record the following real time data: 1) Threshold height 2) Infant's head lift height and 3) Toy status – on or off. A simple serial port terminal application named CoolTerm was used to export the data from the PPAC in an excel file for further processing and testing. Matlab was used to compute - Duration "Toy ON" (DTO), and Frequency of toy reactivations (FTR) at the end of baseline and each acquisition phase (refer to Table 1 for definition of terms). A short term learning and retention criteria was set a priori that categorized infants as short term learners and retainers of the association learned on day 1, 24 hours later. Infants were categorized as short term learners if their FTR or DTO in any 2 consecutive phases of the final 3 acquisition phases was 1.5 times higher than the FTR and DTO of the baseline on day 1.Retention of the association learned on day 1 was identified if infants FTR and DTO in any 2 consecutive phases of the final 3 acquisition phases on 2nd day of testing was 1.5 times the FTR and DTO of the baseline phase on day 1. Functions in Microsoft Excel were used to identify the infants who met the short term learning and retention criteria.

Data analysis. Descriptive statistics were used to describe the study sample. In order to determine if 3-6 month old infants demonstrated associative learning, the percentage of infants who were categorized as short term learners was calculated from the processed data from day 1 of testing. The percent of learners meeting the 2 learning criteria were described. In addition, the percentage of infants who learned on day 2 was calculated. In order to determine if 3-6 month old infants demonstrated retention of associative learning, data from the infants who learned on day 1 was used to identify percentage of infants demonstrating retention of the association, 24 hours later.

To further understand the infant learning, a post hoc analysis plan was developed to evaluate when in the protocol infants began to demonstrate short term learning. Descriptive statistics were used to describe differences between the 1) short term learners and non-learners and 2) retainers of the association learned and non-retainers. Both the FTR and DTO dataset was tested for normality. The FTR data had a poisson distribution thus a non-parametric Friedman test was used for analysis conducted to evaluate phase differences in the FTRs within the short term learners. Wilcoxon rank-sum was used to compare differences in FTR between the short term learners and non-learners. The DTO data was normally distributed hence we used a Repeated Measure Analysis of Variance (RMANOVA) to compare the effects of phase of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4) on the DTO among the short term learners. An independent t test was used to compare differences in the DTO between the short term learners and non-learners of the association in prone. Wilcoxon rank-sum test was used to compare the baseline FTRs on day 1 and day 2 of testing of learners, non-learners, retainers and non-retainers. Paired sample t test was used to compare the baseline DTO on day 1 and day 2 of testing of learners, non-learners, retainers and non-retainers. All the exploratory factors were descriptively described. Statistical analyses were completed using SPSS version 24 with alpha level set at 0.05 for the test statistics values and adjusted using a Bonferroni correction (adjusted $\alpha = 0.0125$).

Results

Twenty eight infants met the inclusion criteria and were enrolled in the study. The average age of infants who participated in this study was 5 (0.9) months. The sample was 54 % girls, 85 % White and 100 % of non-Hispanic origin (Table 2). A total of 6 infants' data was not included in the analysis; in 3 infants testing was stopped due to crying for more than 30 seconds continuously precluding baseline data collection, data from 2 infants was not usable because they often moved out of the PPAC sensor's coverage area by scooting backwards in prone and 1 infant's data file was corrupted and could not be processed leaving an analyzable sample of 22 infants whose data were included in this analysis.

Sixty four percent (n=14) of the infants met our learning criteria on day 1 and were categorized as short term learners of the association in prone positon. (Table 3 and 4) Of the 8 infants who did not demonstrate operant conditioning based on defined criteria on day 1five of these eight infants participated in day 2 testing. Of these, one infant demonstrated short term learning on day 2 of testing.

Of the 14 infants who demonstrated short term learning on day 1 and should have been assessed for retention on the second day of testing, 1 infant was sick, 1 infant missed the visit and 3 infants did not complete the testing due to excessive crying in the 3rd acquisition phase, leaving a sample of 9 short term learners on which to assess retention. Three of nine (33%) of the short term learners demonstrated retention from day 1 to day 2. (Table 4)

Phase comparison within short term learners and non-learners. Findings from the Friedman test suggested a significant difference in the FTRs of short term learners within the 5 phases of testing. (χ^2= 21.48, p = .003). Short term learners increased their FTRs significantly from baseline to Acq 1 (χ^2= -1.90, p = .007), Acq 2 (χ^2= -2.3, p = .001) and Acq 3 (χ^2= -2.25, p = .001). No significant difference was seen between baseline and Acq 4 (χ^2= -.50, p =.48) for the short term learners (Figure: 2). RMANOVA results indicated a significant difference in the DTO among the short term learners within the 5 phases of testing [F(4,7) = 7.19, p =.000] . Pairwise comparisons revealed that short term learners significantly increased their DTO from baseline by an average of 25.6 seconds in Acq 1 (p =.027), 21.4 seconds in Acq 2 (p =.016) and 27.7 seconds in Acq 3 (p=.001). Post Bonferonni correction only the difference seen in DTO between baseline to Acq 3 survived. No significant difference in the mean DTO was seen between baseline and Acq 4 (p=1.0) for the short term learners (Figure: 3).

In contrast to the short term learners, no significant difference was seen in the FTRs (χ^2= .364, p = .98) and DTO [F(1,4) = 1.06, p =.40] within the baseline and acquisition phases of testing among the non-learners on day 1 of testing.

Phase comparisons between the short term learners and non-learners. A direct comparison of the learners and non-learners FTR and DTO was used to quantify difference in the performance pattern during the testing protocol. The Wilcoxon rank-sum test indicated a significant difference in the FTRs between the short term learners and non-learners at Acq 1 (Z = -2.62, p = .008), Acq 2 (Z= -2.59, p = 0.01) and Acq 3 (Z = -2.55, p = .01) (Figure 4). No significant group difference was found in FTRs at baseline (Z =-.67, p =0.57), and Acq 4 (Z= -0.83, p = 0.40). For the DTO, t test statistics suggested a significant difference at Acq 1 [t(20) = -2.86, p = 0.00], Acq 3 = [t(20) = -3.12, p = 0.00] (Figure: 4) and no significant differences between the groups was seen at baseline [t(20)= 1.78, p = 0.08], Acq 2 [t(20) = -0.89, p =0.38] and Acq 4 = [t(14) = -0.94, p = 0.36].

Day 1 vs day 2 baseline FTRs and DTO comparisons- evaluation of retention of learning during day 2 baseline. No significant difference was found between the baseline FTRs on day 1 and day 2 of short term leaners (Z = 1.20, p = .22) and non-learners on day 1 of testing (Z = 1.50, p = .414). Similar results were seen when the day 1 and day 2 baseline DTO of learners [t(11)= -.805, p = 0.44] and non-learners [t(4)= .950, p = 0.39] were compared against each other. However, 40 % of the short term learners had a 1.5 times higher FTRs on the 2nd day's baseline compared to day 1's baseline.

No statistical significant difference was seen in the day 1 and day 2 baseline's FTRs (Z = 1.84, p = .06) and DTO [t(5)-=.50, p=.64] of short term learners who did not retain the association a day later (non retainers). However, 60 % of the non-retainers had a 1.5 times higher FTRs on 2nd day's baseline compared to day 1's baseline. Similarly, no significant difference was seen in the day 1 and day 2 baseline's FTRs (Z = 1.34, p =.18) and DTOs [t(2) = -.1.91, p=.19] of infants who retained the association a day later.

Exploratory factors impacting learning. A 2 tailed independent t test showed that infants' age (p=.61) and AIMS prone score (p= .19) did not differ between the groups. However, a higher percentage of short term learners completed the testing compared to the non-learners (Table 5).

Discussion

Our findings support that when 3-6 months old infants born at full term are presented with a task of raising their head to a certain height to activate a toy, a majority of infants tend to associate their movements with the activation of the toy. Our results are similar with previous associative learning studies in which 50 – 80 % of infants showed associative learning with the mobile paradigm at 3-6 months of age[9,12,26–28]. Our associative learning paradigm in prone is most in line with the modern mobile paradigm developed by Sargent et al, 2015. Corresponding to the modern mobile paradigm which had a virtual threshold and a “3 seconds rule” our paradigm had a virtual threshold set at infants’ AHH and a “10 seconds rule”. The virtual threshold allowed infants to independently discover the association as they push themselves up on forearms or hands in prone position after the toy automatically turned off even if the infants’ head is above the threshold. Infants in our paradigm had to lower than raise their head to the height at or above the virtual threshold to activate the toy again. Findings from our study are in line with the modern mobile paradigm, where 30 % of infants demonstrated learning on day 1 and 35 % retained the association on day 2. It is important to note that our criteria to identify short term learners and retainers was similar to the work of Sargent on the modern mobile paradigm. However, the modern mobile paradigm used different terms than ours. What Sargent referred to as “performance” we referred to a “short-term learning”. In the modern mobile paradigm, from a total sample of 14 infants only 4 infants performed on day 1 and 10 infants performed on day 2. Based on the high performance rate seen on the 2nd day of testing in the mobile paradigm, we expected some infants would need more practice and included a 2nd day of testing that provides the exact same experience as on the 1st day of testing. Contradictory to our expectation, we found a majority of our non-learners did not learn even after an extra day of practice. We believe that infants’ tolerance for prone position and motor skills in prone may support their ability to learn the association between their upper body movements and the activation of a toy. Although we screened infants for their tolerance and motor skills in prone to determine eligibility, we had infants who clearly “liked” tummy time as well as infant who passed the screening but were tired after 5-6 minutes in to the testing. This may explain a higher percent of non-learners not being able to complete the last acquisition block of testing compared to the short term learners.

The majority of infants did not meet our criteria to be identified as retaining the association between their movements and the activation of the toy, 24 hours later. Our second finding is in contrast to 3-4 months old infants born at full term retaining the association between their tethered leg and movement of the mobile, 24 hours and a week later. However, we saw a similar retention rate compared to the modern mobile paradigm where only 35 % of infants had a 1.5 times higher kicking response compared to the previous day's baseline. A possible explanation to the discrepancy found in the retention rate of infants among different paradigms could be due to: 1) the modern mobile paradigm and our paradigm in prone being more challenging to learn and retain than the traditional mobile paradigm and 2) obstruction of the retention of the short term learning by introducing a contradicting experience of the toy not activating in response to the infant's upper body movements during the baseline on the 2nd day of testing 3) our method of providing a break between 2 minute blocks of acquisition. Our paradigm in prone and the modern mobile paradigm may be are more cognitively and motorically challenging for infants than the traditional mobile paradigm. In both these modern paradigms infants had to independently perceive the effect created by their own body's movement, without any external cue, such as the sensory input from the tether. The association presented to infants was not simply a cause and effect task. Infants were required to change their movement pattern to learn the association and this may make it more difficulty to retain a day later. The criteria we used for the categorization of infants as short term learners and retainers did not include an infant's interaction during the baseline phase on 2nd day of testing. However, descriptively we saw an increase in the FTRs and DTO in the baseline phase of day 2 of testing (FTR =1.83 ± 1.72, DTO = 32.89 ± 6.77) compared to day1 (FTR = 0.76 ± .92, DTO = 28.59 ± 13.85) (Table 3 and 4). It is possible that infants did associate their movements with the toy in the beginning of the 2nd day of testing but lost interest or became frustrated during the baseline period when the toy did not move at all. The finding that the retainers continued to increase their FTR while the non-retainers decreased with FTR after baseline 2 support this potential limitation.

Tasks that allows for an adequate amount of time for self-initiated, trial and error discovery periods may benefit motor learning in prone position. A gradual increase was seen in the FTRs and DTO of infants who learned the association on day 1 of testing. Short term learners had the highest learning response between 4 – 8 minutes (Acq 2- 3) (Figure: 1 and 2) in a 10 minute session. This provides an idea of the practice infants may need before any learning effect can be seen. Although 4 minutes of "practice time" may seem to be a short period of time, it is important to consider this need for 4 or more minutes of free play when an intervention is designed to allow infants to independently explore and discover contingencies around them.

Limitations

A potential limitation of our study was the high dropout rate due to infants' intolerance for prone position and wear and tear of the PPAC leading to technical failures during the assessments. These issues can be solved in the future by changing the eligibility criteria to infants who can tolerate 10 minutes of prone play and improving the efficiency of the technology by building a more sturdy prototype. Also, we prioritized the assessment of short term learning on the 2nd day of testing and added a baseline phase in the 2nd day of testing. This turned out to be a limitation of our protocol to assess retention in infants as we believe by providing an experience of toy not activating in response to head lifts on the 2nd day of testing we may have interfered with the association learned on day 1. Our small sample size limited our ability to do a detailed analysis of the factors such as infants' age, tolerance for prone, motor skills in prone, problem solving abilities that may predict short term learning of an association in prone position in infants.

Clinical Relevance

With this study we are providing two avenues for physical therapist to contemplate in their practice: 1) The PPAC and an associative learning paradigm may have the potential to detect early motor learning delays in infants or the impact of atypical motor control on early learning and 2) The ability to measure learning using this prone associative learning paradigm may lead to the developmental of associative learning based intervention to train infants to modify their motor control in prone. We certainly need to extensively research these avenues to translate them in to practice. This paradigm with some modifications may be useful in providing reinforcement specific activity and providing an environment with highly repeatable positive reinforcement to increase the dose of practice. The temporal and spatial features of the task provides an infant with opportunities to learn the anticipatory and predictive piece of skill development consistent with the interplay between motor and cognitive skills in early learning.

References

1. Thelen E. Dynamic Systems Theory and the Complexity of Change. *Psychoanal Dialogues*. 2005. doi:10.1080/10481881509348831

2. Von Hofsten C. An action perspective on motor development. *Trends Cogn Sci*. 2004;8(6):266-272. doi:10.1016/j.tics.2004.04.002

3. Savelsbergh GJP, Vereijken B, Zaal FTJM. Putting the "motor" back into development: The legacy of Esther Thelen (1941-2004). *Infant Behav Dev*. 2005;28(2):97-98. doi:10.1016/j.infbeh.2005.02.006

4. Rovee-Collier C. Shifting the focus from what to why. *Infant Behav Dev*. 1996. doi:http://dx.doi.org/10.1016/S0163-6383(96)90001-6

5. Rovee-Collier C. Learning and memory in infancy. In: *Handbook of Infant Development (2nd Ed.). Wiley Series on Personality Processes*. ; 1987.

6. Rovee-Collier CK, Gekoski MJ. The economics of infancy: a review of conjugate reinforcement. *Adv Child Dev Behav*. 1979;13:195-255.

7. Sargent B, Schweighofer N, Kubo M, Fetters L. Infant exploratory learning: Influence on leg joint coordination. *PLoS One*. 2014;9(3). doi:10.1371/journal.pone.0091500

8. Sargent B, Reimann H, Kubo M, Fetters L. Quantifying Learning in Young Infants: Tracking Leg Actions During a Discovery-learning Task. *J Vis Exp*. 2015;(100):e52841. doi:10.3791/52841

9. Sargent B, Kubo M, Fetters L. Infant Discovery Learning and Lower Extremity Coordination: Influence of Prematurity. *Phys Occup Ther Pediatr*. 2017;2638:1-16. doi:10.1080/01942638.2017.1357065

10. Chen CY, Harrison T, Heathcock J. Infants with complex congenital heart diseases show poor short-term memory in the mobile paradigm at 3 months of age. *Infant Behav Dev*. 2015;40:12-19. doi:10.1016/j.infbeh.2015.02.007

11. Me L, Heathcock J. The Relative Kicking Frequency of Infants Born Full-term and Preterm During Learning and Short-term and Long-term Memory Periods of the Mobile Paradigm. *Phys Ther*. 2005;(June). doi:10.1093/ptj/85.1.8

12. Heathcock JC, Bhat AN, Lobo MA, Galloway JC. Research Report The Performance of Infants Born Preterm and Full-term in the Mobile Paradigm : Learning and Memory. 2004;(June). doi:10.1093/ptj/84.9.808

13. Heathcock JC, Bhat AN, Lobo MA, Galloway JC. The relative kicking frequency of infants born full-term and preterm during learning and short-term and long-term memory periods of the mobile paradigm. *Phys Ther*. 2005;85(1):8-18.

14. Rovee-Collier C. The rise and fall of infant classical conditioning research: Its promise for the study of early development. *Adv Infancy Res*. 1986.

15. Gerhardstein P, Kraebel K, Tse J. Using operant techniques with humans infants. *Behav*

Anal Today. 2006;7(1):56-70. http://www.biomedsearch.com/article/Using-operant-techniques-with-humans/170113005.html.

16. Standley JM. The effect of music-reinforced nonnutritive sucking on feeding rate of premature infants. *J Pediatr Nurs*. 2003;18(3):169-173. doi:10.1053/jpdn.2003.34

17. Chorna OD, Slaughter JC, Wang L, Stark AR, Maitre NL. A Pacifier-Activated Music Player With Mother's Voice Improves Oral Feeding in Preterm Infants. *Pediatrics*. 2014;133(3):462-468. doi:10.1542/peds.2013-2547

18. Williams JL, Corbetta D. Assessing the impact of movement consequences on the development of early reaching in infancy. *Front Psychol*. 2016;7(APR):1-15. doi:10.3389/fpsyg.2016.00587

19. Taub E, Crago JE, Uswatte G. Constraint-induced movement therapy: a new approach to treatment in physical rehabilitation. *Rehabil Psychol*. 1998;43(2):152-170. doi:10.1037/0090-5550.43.2.152

20. Zachry AH, Kitzmann KM. Caregiver awareness of prone play pecommendations. *Am J Occup Ther*. 2011;65(1):101-105. doi:10.5014/ajot.2011.09100

21. Back to Sleep, Tummy to Play. https://www.healthychildren.org/English/ages-stages/baby/sleep/Pages/Back-to-Sleep-Tummy-to-Play.aspx. Published 2017.

22. Adolph KE, Vereijken B, Denny MA. Learning to Crawl. *Child Dev*. 2008;69(5):1299-1312. doi:10.1111/j.1467-8624.1998.tb06213.x

23. Thelen E. Many roads lead to Rome: Locomotion and dynamics. *Infancy*. 2000;1(2):221-224. doi:10.1207/S15327078IN0102_2

24. Christy JB, Lobo MA, Bjornson K, et al. Technology for children with brain injury and motor disability: ExecutIVe summary from research summit IV. *Pediatr Phys Ther*. 2016;28(4):483-489. doi:10.1097/PEP.0000000000000317

25. Schreiber JB, Stage FK, King J, Nora A, Barlow EA. Reporting structural equation modeling and confirmatory factor analysis results: A review. *J Educ Res*. 2006;99(6):323-337. doi:10.3200/JOER.99.6.323-338

26. Haley DW, Grunau RE, Oberlander TF, Weinberg J. Contingency learning and reactivity in preterm and full-term infants at 3 months. *Infancy*. 2008;13(6):570-595. doi:10.1080/15250000802458682

27. Lobo MA, Galloway JC. Assessment and stability of early learning abilities in preterm and full-term infants across the first two years of life. *Res Dev Disabil*. 2013;34(5):1721-1730. doi:10.1016/j.ridd.2013.02.010

28. Rovee-Collier C. Dissociations in Infant Memory: Rethinking the Development of Implicit and Explicit Memory. *Psychol Rev*. 1997;104(3):467-498. doi:10.1037/0033-295X.104.3.467

Tables

Table 1: Terms and abbreviations used in the protocol

Term (abbreviation)	Definition	How obtained/calculated
Head lift height (HH)	Distance from the highest point on the infant's head to floor.	Calculated by the PPAC
Average head lift height (AHH)	Infant's average head lift height during the trial.	Calculated from the data from PPAC
Threshold height (TH)	Height set by the experimenter at which the toy turns ON.	Equals AHH during the Pre-baseline trial
At or Above Threshold (AT)	Infant's head is equal to or higher than a threshold height	
Duration of Toy ON (DTO)	Duration of a continuous episode of AT during the trial with a maximum of 10 seconds	Matlab was used to calculate the DTO
Frequency of toy reactivations (FTR)	Frequency of reactivations after meeting a maximum of 10 seconds	Matlab was used to calculate the FTR

Table 2 : Demographics of included infants (N = 22)

Age	5.0 (0.9) months (3.45 – 5.9 months)
Gender	
Female	54 %
Ethnicity	
Not Hispanic or latino	100 %
Race	
African American	5 %
Asian	10 %
White	85 %

Table 3: Descriptive statistics of Frequency of toy reactivations in short term learners and non learners

Day 1 testing	Baseline M (SD)	Acquisition 1 M (SD)	Acquisition 2 M (SD)	Acquisition 3 M (SD)	Acquisition 4 M (SD)
Short term learners (n = 14)	0.76 (.92)	2.38 (1.66)	2.78 (1.42)	2.53 (1.39)	1.3 (1.42)
Non-learners (n= 8)	0.75 (1.38)	0.75(1.75)	1.0 (1.19)	0.75 (1.75)	0.8 (1.30)

Duration of toy ON (in seconds) in short term learners and non learners

Short term learners (n = 14)	28.59 (13.85)	53.13 (13.80)	59.71 (11.48)	50.21(7.46)	38.01(17.06)
Non-learners (n= 8)	37.06 (21.71)	39.36 (11.38)	45.68 (21.60)	36.10 (16.88)	32.61(30.29)

Table 4: Descriptive statistics of Frequency of toy reactivations in retainers vs non retainers

Day 2 testing	Baseline _FTR M(SD)	Acquisition 1_FTR M(SD)	Acquisition 2_FTR M(SD)	Acquisition 3_FTR M(SD)	Acquisition 4_FTR M(SD)
Retainers (n = 3)	1.5 (0.83)	3.0(1.0)	4.0 (2.16)	3.0 (2.14)	2.0 (1.90)
Non-retainers (n= 6)	1.83 (1.72)	1.5 (1.37)	1.16 (1.6)	0.6 (1.63)	0.16(0.40)

Duration of toy ON (in seconds) in retainers vs non- retainers

Retainers (n = 3)	32.44(20.27)	50.62 (6.25)	52.98 (11.25)	47.04 (10.02)	54.23 (21.64)
Non-retainers (n= 6)	32.89 (6.77)	49.31(19.37)	34.58 (13.57)	34.93(23.32)	23.56 (14.47)

Table 5: Exploratory factors impacting learning

	Short term Learners	Non-learners
Age in months M(SD)	4.9 (.75)	5.10 (1.08)
AIMS prone skills score M(SD)	7.21 (1.12)	6.5 (1.3)
Percentage of infants who completed the last block of testing in the acquisition phase	79 %	62 %

Figures

Figure legends

Figure 1: Prone Play Activity Center. Note: The translucent triangle represents a not on scale area of the ultrasonic sensors, sensing the position of infant's head in space. The red line represents the height of the virtual threshold.

Figure 2: Within group comparison of short term learners FTRs at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (n = 12). Error bar represents standard deviation

Figure 3: Within group comparison of the short term learners DTO at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (n = 12)). Error bar represents standard deviation

Figure 44: Group comparison between learners and non-learners FTRDTO at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (short term learner; n = 12 and non learner; n=5)). Error bar represents standard deviation

Figure 5: Group comparison between learners and non-learners DTO at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (short term learner; n = 12 and non learner; n=5)) Error bar represents standard deviation

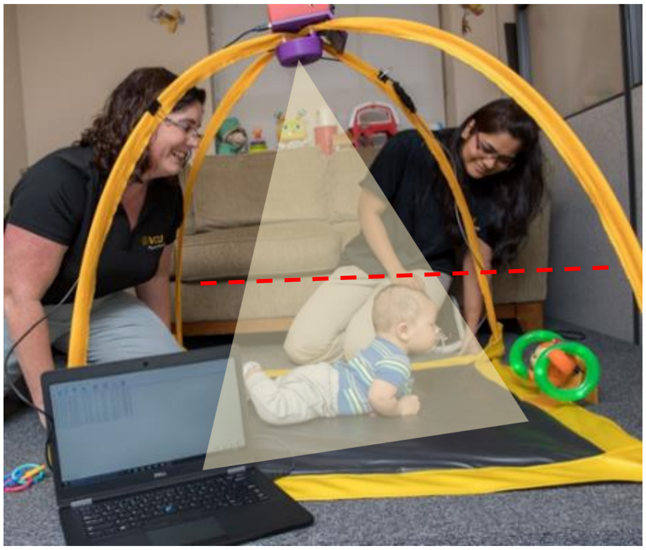

Figure 1: Prone Play Activity Center

Note: The translucent triangle represents a not on scale area of the ultrasonic sensors, sensing the position of infant's head in space. The red line represents the height of the virtual threshold.

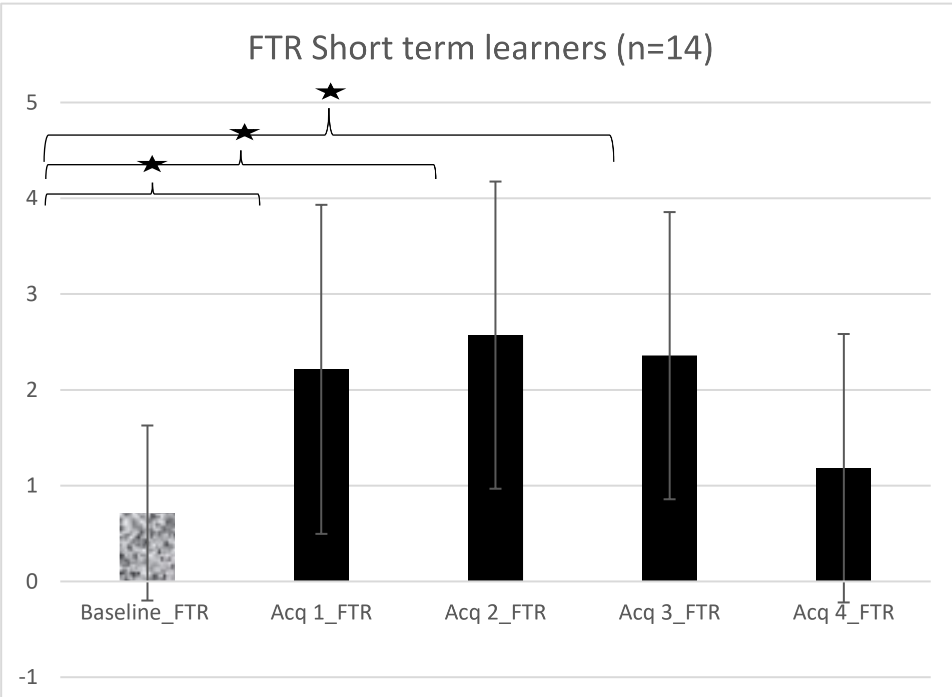

Figure 2: Within group comparison of short term learners FTRs at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (n = 12). Error bar represents standard deviation.

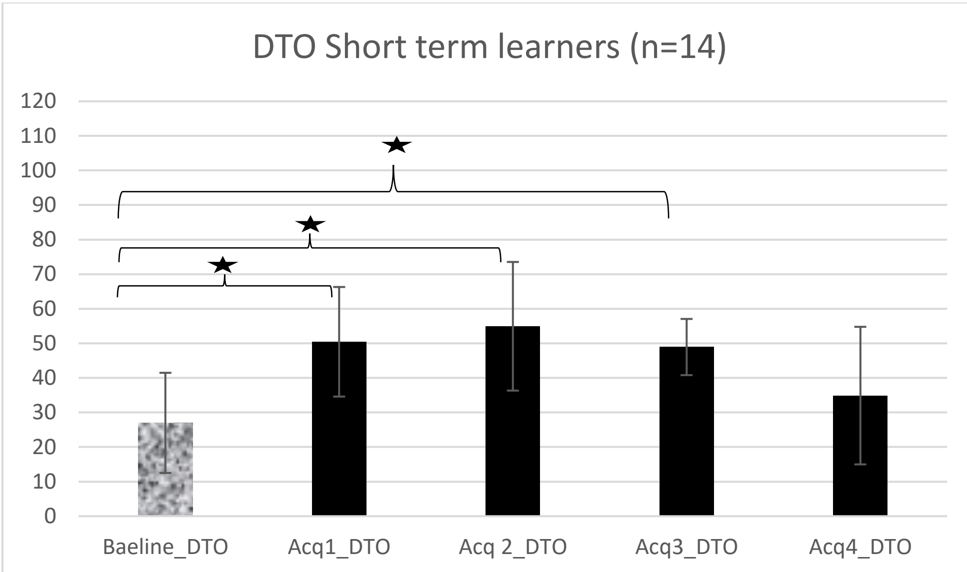

Figure 3: Within group comparison of the short term learners DTO at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (n = 12)). Error bar represents standard deviation

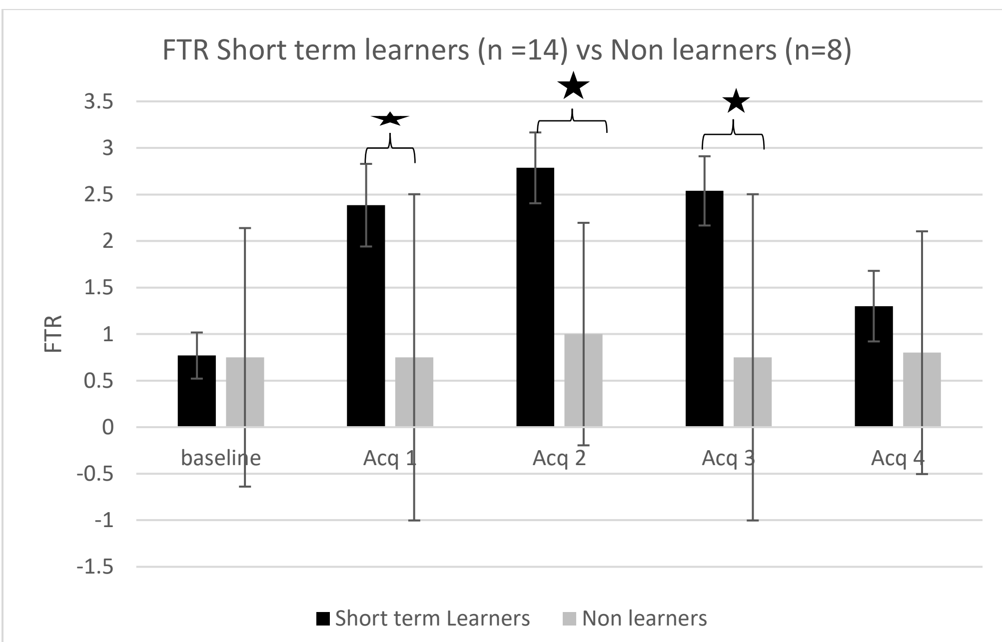

Figure 4: Group comparison between short term learners and non-learners FTR at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (short term learner; n = 12 and non learner; n=5)). Error bar represents standard deviation

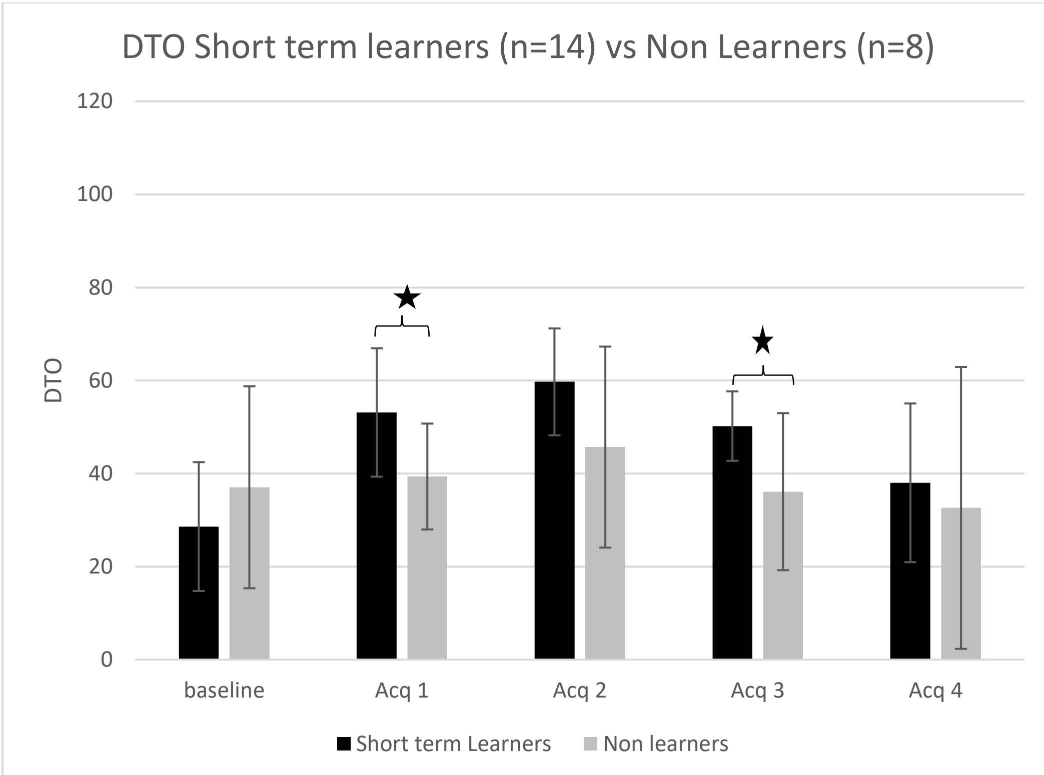

Figure 5: Group comparison between short term learners and non-learners DTO at 5 phases of testing (Baseline, Acq 1, Acq 2, Acq 3 and Acq 4 (short term learner; n = 12 and non learner; n=5)) Error bar represents standard deviation

Chapter 5: Conclusion

Three independent, but related studies were conducted in partial fulfillment of a Doctorate of Philosophy in the Rehabilitation and Movement Sciences Program at Virginia Commonwealth University. The purpose of the first was to develop the technology and protocols used in the other 2 studies. The purpose of the second to determine if 3-6 months old infants can demonstrate associative learning in prone. The purpose of the third was to evaluate the feasibility of using a high technology intervention based on the principles of motor learning and associative learning to increase infants' prone tolerance and improve motor outcomes. Findings from these projects suggests that: 1) infants can independently discover the association between their head and upper body movements and the activation of a toy, 2) during the discovery/associative learning process the majority of infants learned to change their motor behavior in prone to keep the toy on for longer periods of time and 3) both the high technology intervention that uses an automated play center to positively reinforce the infants head and upper body movements and a dose matched low tech educational condition based on usual care are feasible interventions. 4) measurement of changes in the infant's prone tolerance and motor development following the intervention is feasible. The purpose of this chapter is to synthesize our findings to guide researchers and physical therapists specialized in pediatric rehabilitation.

We will discuss our contributions to the field of pediatric physical therapy and pediatric research under four themes: 1) Significance and Innovation 2) Quantification of motor learning in prone 3) Combination of technology and motor learning to develop interventions 4) Next steps.

Theme 1: Significance and Innovation

The significance of our innovation lies in the importance of understanding prone motor behavior of infants and developing strategies to positively impact prone motor skills. Play in prone position provides infants with opportunities to develop strength and coordination in the neck, trunk and upper extremities musculature.(Dudek-Shriber & Zelazny, 2007; Zachry & Kitzmann, 2011a) Prone play is important to counteract the adverse effects of spending an excessive amount of time in a supine position or contained in equipment such as seating device.(J. Guidetti et al., 2017) Although the importance of prone play is well recognized among parents, pediatricians and therapists, prone play is often reported as a challenge for parents and therapists to implement in an infants' routine.(Zachry & Kitzmann, 2011a) Infant's poor tolerance for prone has been identified as a factor contributing towards lack of prone play in an infant's routine. (Dudek-Shriber & Zelazny, 2007; J. M. Guidetti, 2011; J. Guidetti et al., 2017; Zachry & Kitzmann, 2011b) Current approaches are ineffective due to inconsistent information on dose ("how much" or "how early" to begin prone play) or what "active ingredients" are vital to bring a meaningful change in infant's tolerance for prone and maximize outcomes.(Koren et al., 2010b) Thus, it was important to begin to evaluate alternative strategies and interventions based on current knowledge of developmental and motor learning theory.

Today, advances in technology have empowered movement specialists to build rehabilitation devices that have the potential to assess and optimize movement interventions. From sensor onesies(Rogers et al., 2015) designed to promote early movements in infants with developmental delays to exoskeletons such as Hybrid Assistive Limb Cyberdyne(Matsuda et al., 2018) developed to promote locomotion in individuals with spinal cord injury, technology has shown promise in adapting to our growth and functional abilities. Through our collaboration with biomedical engineers and art professionals we built an instrumented play center, Prone Play Activity Center (PPAC) with the purpose of enhancing our ability to measure infant learning and to provide infants with opportunities to practice a behavior utilizing motor and cognitive skill, with reinforcement, which might improve tolerance for prone play and advance their prone motor skills.

The PPAC and our assessment and training protocols are grounded in the theories of motor learning. Motor learning is described in the literature as *"set of processes associated with practice or experience leading to a relatively permanent change in the capability for producing skilled action"*.(Shumway-Cook, A., & Woollacott, 2007) Based on the contemporary view of infant development, infants learn to acquire a skill through their interaction with the environment.(Thelen, 1995a, 1998, 2005) Exploration through self-initiated movement provides natural opportunities to infants to find a purpose in their actions and gain the knowledge or perception of the movement itself and the environment.

The conception and development of the PPAC was completed through an innovative integration of our knowledge of infant development and motor learning with technology to advance developmental science and pediatric rehabilitation. Technology development is a time intensive process, usually requires multiple iterations, preliminary data to understand its applicability/feasibility and high quality research trials to determine efficacy. The development and use of the PPAC, an innovative rehabilitation device, allowed us to answer questions that would be impossible without this technology.

Theme 2: Quantification of Motor Learning in Prone

Assessment of learning in infants is an ongoing challenge for developmental researchers as learning in itself cannot be measured directly; instead, it is inferred based on infant's behavior.(Shumway-Cook, A., & Woollacott, 2007) For the assessment of motor learning, learning paradigms are developed to associate a motor behavior of interest with a purpose that is measurable. For instance the modern mobile paradigm (Sargent, Reimann, et al., 2015) uses wearable sensors to quantify infants' kicking response and uses computational technology to create an effect on a mobile when the infant kicks to a certain height.

The associative learning paradigm used in this project is a unique measure of motor learning in prone, a position of importance to enhance motor development and prevent positional deformities. Motor behaviors that have been studied most commonly with the use of associative learning paradigms in infants are kicking and reaching.(C. Rovee-Collier, 1987) These behaviors share some properties such as infants early in development move their upper and lower limbs spontaneously in a rhythmic manner.(Thelen, 1995b) The mobile paradigm originally developed with kicking as the behavior of interest was adapted with ease to understand the skill of reaching in infants.(Taylor et al., 2013) However, with limited research on mechanics of infant's prone motor behaviors, adaptation of the mobile paradigm in prone in itself was a challenge. Our learning paradigm overcame this barrier and opened up possibilities for researchers to utilize this paradigm to learn about prone motor control in infants. With the use of this technology and paradigm we were able to quantify and evaluate changes in infants' prone motor behavior in response to a motor learning challenge. Interestingly, infants were able to activate the toy a minimum of 1.5 times higher than the baseline phase, a phase where the toy activation was not associated with infants' movements. Within a 10 minute session the majority of infants were able to learn the association between their head and upper body movements and the activation of a toy. Infants who were able to complete all 8 minutes, 4 blocks of 2 minutes, appeared more likely to learn the paradigm than those who fatigued after 3 blocks of 2 minutes. In addition, those infants who were more tolerant of prone positioning at baseline were more likely to learn the paradigm. While these finding support the use of the associative learning assessment in prone, it also highlights the importance of adequate practice to learn the association. If verified, the understanding that 8 minutes is more effective than 6 minutes to support learning could help inform future intervention protocol using this associative learning paradigm. Our finding that most 3-6 months old infants can demonstrate short term learning in prone is valuable as it supports the potential for infants to learn a challenging task in prone, early in development. Quantification of motor learning in typically development infants helps developmental scientists understand the role of infants' interaction in environment on their learning.

Theme 3: Integration of Principles of Motor Learning in Intervention Practices

At Research Summit IV "Innovations in Technology for Children with Brain Insults: Maximizing Outcomes" hosted by the Academy of Pediatric Physical Therapy of the APTA, an expert in the field of rehabilitation science, asserted that, "*in order to maximize motor gains and clinical outcomes, researchers must design and test innovative and targeted interventions tailored to the individual child".*(Christy et al., 2016) We modified a modern learning assessment paradigm to assess associative learning in prone and developed an innovative intervention which could be tailored to an individual child's abilities and is targeted to the need of prone play in an infants' routine.

The use of the PPAC and our training protocol to promote daily opportunities to enhance motor learning through self-directed movements in prone is feasible. While feedback from parents on the feasible dose of intervention will help us modify the protocol, parents were able to implement the key components of the intervention – positive reinforcement to infants' initial efforts to play in prone and encourage infants to raise their upper body higher by identifying the "Just Right Challenges". The ability of parents to incorporate a 3 week, home based- high tech intervention in their infant's routine independently is a promising finding for researchers and physical therapist who wish to combine technology with their practice. Some common factors identified in the literature that are responsible for the decline of technology in pediatric rehabilitation are the technology being bulky, not aesthetically pleasing, parents feel their child is wired up and the child grows out of it.(Christy et al., 2016) From the conception of the PPAC we were cognizant towards the factors that can make the use of technology at home challenging for the parent. Through multiple careful adaptations to the design and instrumentation during the iteration of the PPAC, we were able to build a parent and child friendly device that is feasible to use at home. A high percent of parents in the high tech group of intervention used the PPAC and adhered to the active ingredients of the intervention. While preliminary in nature, the changed in prone tolerance and motor development are promising and provide the preliminary data needed to plan an efficacy study.

Theme 4: Next Steps

The finding from both the study of associative learning and the feasibility of our High-tech intervention have set the stage for a meaningful line of research. First, we plan to replicate our study of associative learning with slight modifications to the protocol to enhance our ability to evaluate retention of learning. We assessed infants for short term learning and retention in our study. However, the use of a baseline phase on day 2 may have limited our ability to assess retention in some infants who were easily frustrated as the toy would not activate in response to their upper body movements for the first 2 minutes on day 2 of testing. Thus the paradigm may need to be different if the goal is to demonstrate learning each day vs evaluating retention. In the motor learning literature, learning is described as a relatively permanent change in behavior. Thus, we also need to follow infants for a longer period of time, such as a week after the initial learning, to determine if they retain the association in prone.

Second, we plan to extend our findings from the feasibility study to design a larger study to test the efficacy of the high technology intervention to advance prone tolerance and motor skills in infants with high and low risk of developmental delays. The feedback from parents and experiences using the PPAC have provided valuable feedback on modification to both the device and the training protocol.

Third, a study should be designed to determine the motor control patterns used by in infants who learned the paradigm in prone. The use of motion capture systems and/or wearable sensors and possible electromyography (EMG) to gain information on coordination of multiple head and upper body segments and muscle activation patterns would provide valuable information on how an infant's prone motor control is adapting during associative learning. This knowledge may help to modify the technology to support toy activation when movement patterns fall within a specific range. If infants with neurological insults and limited motor control could be provided with individualized reinforcement to encourage a specific range of movement during self-directed play, this approach could revolutionize the way we provide rehabilitation to infants with brain injury.

Last, future research may consider the implications of learning on the development and plasticity of the brain. Thus, assessment of neural mechanisms and structures responsible for associative learning or that change through the learning process may be appropriate.

Together the steps forward represents a lifetime of work that supports the fields of developmental science and pediatric rehabilitation. While at the beginning of my research career, I recognize that this dissertation research has supported my skills to develop innovative, precise research designs, see the value of collaboration with parents and other disciplines, introduce a novel line of research in pediatric rehabilitation and most importantly has solidified my interest for science and passion for lifelong learning.

References

Abbott, A., & Bartlett, D. (2001). Infant motor development and equipment use in the home. *Child: Care, Health and Development*, *27*(3), 295–306. https://doi.org/10.1046/j.1365-2214.2001.00186.x

Adolph, K. E., & S. Kretch, K. (2015). Learning to Perceive or Perceiving to Learn? *International Encyclopedia of the Social and Behavioral Sciences*, 127–134. https://doi.org/10.1016/B978-0-08-097086-8.23096-1

Angulo-barroso, R. M., Peciña, S., Lin, X., Li, M., Sturza, J., Lozoff, B., … Sturza, J. (2016). Implicit learning and emotional responses in nine- month-old infants, *9931*(May). https://doi.org/10.1080/02699931.2016.1179624

Angulo-kinzler, R. M., & Horn, C. L. (2001). Selection and memory of a lower limb motor-perceptual task in 3-month-old infants, *24*, 239–257.

Argenta, L. C., David, L. R., Wilson, J. A., & Bell, W. O. (1996). An increase in infant cranial deformity with supine sleeping position. *Journal of Craniofacial Surgery*. https://doi.org/10.1097/00001665-199601000-00005

Back To Sleep, Tummy To Play. (2008).

Bartlett, D. J., & Fanning, J. E. K. (2003). Relationships of equipment use and play positions to motor development at eight months corrected age of infants born preterm. *Pediatric Physical Therapy*, *15*(1), 8–15. https://doi.org/10.1097/01.PEP.0000051693.49199.41

Bialocerkowski, A. E., Vladusic, S. L., & Wei Ng, C. (2008). Prevalence, risk factors, and natural history of positional plagiocephaly: A systematic review. *Developmental Medicine and Child Neurology*, *50*(8), 577–586. https://doi.org/10.1111/j.1469-8749.2008.03029.x

Bronfin, D. R. (2001). Misshapen heads in babies: position or pathology? *The Ochsner Journal*, *3*(4), 191–199.

Butler, S., & Als, H. (2008). Individualized developmental care improves the lives of infants born preterm. *Acta Paediatrica, International Journal of Paediatrics*, *97*(9), 1173–1175. https://doi.org/10.1111/j.1651-2227.2008.00916.x

Campanella, J., & Rovee-collier, C. (2005). Latent Learning and Deferred Imitation at 3 Months, *7*(3), 243–262.

Chen, C. Y., Harrison, T., & Heathcock, J. (2015). Infants with complex congenital heart diseases show poor short-term memory in the mobile paradigm at 3 months of age. *Infant Behavior and Development*, *40*, 12–19. https://doi.org/10.1016/j.infbeh.2015.02.007

Chen, Y., Fetters, L., Holt, K. G., & Saltzman, E. (2002). Making the mobile move : Constraining task and environment, *25*, 195–220.

Chizawsky, L. L. K., & Scott-Findlay, S. (2005). Tummy Time! *AWHONN Lifelines*, *9*(5), 382–387.

Christy, J. B., Lobo, M. A., Bjornson, K., Dusing, S. C., Field-Fote, E., Gannotti, M., … Rimmer, J. H. (2016). Technology for children with brain injury and motor disability: ExecutIVe summary from research summit IV. *Pediatric Physical Therapy*, *28*(4), 483–489. https://doi.org/10.1097/PEP.0000000000000317

Collett, B., Breiger, D., King, D., Cunningham, M., & Speltz, M. (2005). Neurodevelopmental implications of “deformational” plagiocephaly. *Journal of Developmental and Behavioral Pediatrics*, *26*(5), 379–389. https://doi.org/10.1097/00004703-200510000-00008

Collett, B. R., Aylward, E. H., Berg, J., Davidoff, C., Norden, J., Cunningham, M. L., & Speltz, M. L. (2012). Brain volume and shape in infants with deformational plagiocephaly. *Child's Nervous System*, *28*(7), 1083–1090. https://doi.org/10.1007/s00381-012-1731

Collett, B. R., Gray, K. E., Starr, J. R., Heike, C. L., Cunningham, M. L., & Speltz, M. L. (2013). Development at Age 36 Months in Children With Deformational Plagiocephaly. *Pediatrics*, *131*(1), e109–e115. https://doi.org/10.1542/peds.2012-1779

Collett, B. R., Starr, J. R., Kartin, D., Heike, C. L., Berg, J., Cunningham, M. L., & Speltz, M. L. (2011). Development in toddlers with and without deformational plagiocephaly. *Archives of Pediatrics and Adolescent Medicine*, *165*(7), 653–658. https://doi.org/10.1001/archpediatrics.2011.92

Davis, B. E., Moon, R. Y., Sachs, H. C., & Ottolini, M. C. (1998). Effects of Sleep Position on Infant Motor Development. *Pediatrics*. https://doi.org/10.1542/peds.102.5.1135

DeFrancisco, B. S., & Rovee-Collier, C. (2008). The specificity of priming effects over the first year of life. *Developmental Psychobiology*, *50*(5), 486–501. https://doi.org/10.1002/dev.20313

Dickinson, A. (2001). The 28th Bartlett Memorial Lecture Causal learning : An associative analysis, (July 2000), 3–25.

Dudek-Shriber, L., & Zelazny, S. (2007). The effects of prone positioning on the quality and acquisition of developmental milestones in four-month-old infants. *Pediatric Physical Therapy*, *19*(1), 48–55. https://doi.org/10.1097/01.pep.0000234963.72945.b1

Duggan, M., Lenhart, A., Lampe, C., & Ellison, N. B. (2015). Parents and Social Media. *Pew Research Center*, (July), 1–36. Retrieved from http://www.pewinternet.org/2015/07/16/parents-and-social-media/

Dunst, C. J., Bruder, M. B., Trivette, C. M., & Hamby, D. W. (2006). Everyday activity settings, natural learning environments, and early intervention practices. *Journal of Policy & Practice in Intellectual Disabilities*, *3*(1), 3–10. https://doi.org/10.1111/j.1741-1130.2006.00047.x

Dunst, C. J., Trivette, C. M., Raab, M., & Masiello, T. L. (2008). Early Child Contingency Learning and Detection: Research Evidence and Implications for Practice. *Exceptionality*, *16*(1), 4–17. https://doi.org/10.1080/09362830701796743

Fetters L, Huang HH. (2007). Motor development and sleep,play, and feeding positions in very low birth weight infants with white matter disease. *Dev Med Child Neurol.*, *49*(11), 807–813.

Fitzgerald, H. E., & Brackbill, Y. (1976). Classical conditioning in infancy: development and constraints. *Psychological Bulletin*, *83*(3), 353–376. https://doi.org/10.1037/0033-2909.83.3.353

Fowler, E. A., Becker, D. B., Pilgram, T. K., Noetzel, M., Epstein, J., & Kane, A. A. (2008). Neurologic findings in infants with deformational plagiocephaly. *Journal of Child Neurology*, *23*(7), 742–747. https://doi.org/10.1177/0883073808314362

Galland, B. C., Taylor, B. J., & Bolton, D. P. G. (2002). Prone versus supine sleep position: A review of the physiological studies in SIDS research. *Journal of Paediatrics and Child Health*, *38*(4), 332–338. https://doi.org/10.1046/j.1440-1754.2002.00002.x

Georgieff, M. K., & Bernbaum, J. C. (1986). Abnormal shoulder girdle muscle tone in premature infants during their first 18 months of life. *Pediatrics*, *77*(5), 664–669.

Gerhardstein, P., Kraebel, K., & Tse, J. (2006). Using operant techniques with humans infants. *The Behavior Analyst Today*, *7*(1), 56–70. Retrieved from http://www.biomedsearch.com/article/Using-operant-techniques-with humans/170113005.html

Grossberg, S. (1980). Psychological Review, *87*(1), 1–51.

Guidetti, J. M. (2011). The effectiveness of infant positioning equipment on time spent in wakeful prone, 40. Retrieved from http://utdr.utoledo.edu/graduate-projects

Guidetti, J., Wells, J., Worsdall, A., & Metz, A. E. (2017). The Effect of Positional Support on Tolerance of Wakeful Prone in Infants. *Physical and Occupational Therapy in Pediatrics*, *37*(3), 308–321. https://doi.org/10.1080/01942638.2016.1185506

Hartshorn, K., & Rovee-collier, C. (1997). Infant Learning and Long-Term Memory at 6 Months :

Heathcock, J. C., Bhat, A. N., Lobo, M. A., & Galloway, J. C. (2004a). 7KH 3HUIRUPDQFH RI , QIDQWV % RUQ 3UHWHUP DQG) XOO WHUP LQ WKH 0RELOH 3DUDGLJP / HDUQLQJ DQG 0HPRU \, *84*(9).

Heathcock, J. C., Bhat, A. N., Lobo, M. A., & Galloway, J. C. (2004b). Research Report The Performance of Infants Born Preterm and Full-term in the Mobile Paradigm : Learning and Memory, (June). https://doi.org/10.1093/ptj/84.9.808

Heathcock, J. C., Bhat, A. N., Lobo, M. A., & Galloway, J. C. (2005). The relative kicking frequency of infants born full-term and preterm during learning and short-term and long-term memory periods of the mobile paradigm. *Phys Ther*, *85*(1), 8–18.

Heathcock, J. C., Lobo, M., & Galloway, J. C. (2008). Movement Training Advances the Emergence of Reaching in Infants Born at Less Than 33 Weeks of Gestational Age: A Randomized Clinical Trial. *Physical Therapy*, *88*(3), 310–322. https://doi.org/10.2522/ptj.20070145

Hsu, V. C., Rovee-Collier, C., Hill, D. L., Grodkiewicz, J., & Joh, A. S. (2005). Effects of priming duration on retention over the first 1 1/2 years of life. *Developmental Psychobiology*, *47*(1), 43–54. https://doi.org/10.1002/dev.20071

Hunt, L., Fleming, P., Golding, J., & the ALSPAC Study Team. (1997). Does the Supine Sleeping Position Have Any Adverse Effects on the Child?: I. Health in the First Six Months. *Pediatrics*, *100*(1), e11–e11. https://doi.org/10.1542/peds.100.1.e11

Hunter, J. G., & Malloy, M. H. (2002). Effect of sleep and play positions on infant development: Reconciling developmental concerns with SIDS prevention. *Newborn and Infant Nursing Reviews*, *2*(1), 9–16. https://doi.org/10.1053/nbin.2002.31484

Jones, M. W. (2004). Supine and prone infant positioning: a winning combination. *The Journal of Perinatal Education*, *13*(1), 10–20. https://doi.org/10.1624/105812404X109357

Jongbloed-pereboom, M., Janssen, A. J. W. M., Steenbergen, B., & Sanden, M. W. G. N. Der. (2012). Neuroscience and Biobehavioral Reviews Motor learning and working memory in children born preterm : A systematic review, *36*, 1314–1330. https://doi.org/10.1016/j.neubiorev.2012.02.005

Kane, A. A., Mitchell, L. E., Craven, K. P., & Marsh, J. L. (1996). Observations on a recent increase in plagiocephaly without synostosis. *Pediatrics*, *97*(6 Pt 1), 877–885. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8657530

Kaplan, S. L., Coulter, C., & Fetters, L. (2013). Physical therapy management of congenital muscular torticollis: An evidence-based clinical practice guideline: From the section on pediatrics of the American Physical Therapy Association. *Pediatric Physical Therapy*, *25*(4), 348–394. https://doi.org/10.1097/PEP.0b013e3182a778d2

Kennedy, E., Majnemer, A., Farmer, J. P., Barr, R. G., & Platt, R. W. (2009). Motor development of infants with positional plagiocephaly. *Physical and Occupational Therapy in Pediatrics*, *29*(3), 222–235. https://doi.org/10.1080/01942630903011016

Klimo, P., Lingo, P. R., Baird, L. C., Bauer, D. F., Beier, A., Durham, S., … Flannery, A. M. (2016a). Congress of Neurological Surgeons Systematic Review and Evidence-Based Guideline on the Management of Patients With Positional Plagiocephaly. *Neurosurgery*, *79*(5), E627–E629. https://doi.org/10.1227/NEU.0000000000001428

Klimo, P., Lingo, P. R., Baird, L. C., Bauer, D. F., Beier, A., Durham, S., … Flannery, A. M. (2016b). Congress of Neurological Surgeons Systematic Review and Evidence-Based Guideline on the Management of Patients With Positional Plagiocephaly: The Role of Repositioning. *Neurosurgery*, *79*(5), E627–E629. https://doi.org/10.1227/NEU.0000000000001428

Koren, A., Reece, S. M., Kahn-D’angelo, L., & Medeiros, D. (2010a). Parental Information and Behaviors and Provider Practices Related to Tummy Time and Back to Sleep. *Journal of Pediatric Health Care*. https://doi.org/10.1016/j.pedhc.2009.05.002

Koren, A., Reece, S. M., Kahn-D’angelo, L., & Medeiros, D. (2010b). Parental Information and Behaviors and Provider Practices Related to Tummy Time and Back to Sleep. *Journal of Pediatric Health Care*, *24*(4), 222–230. https://doi.org/10.1016/j.pedhc.2009.05.002

Kuo, Y. L., Liao, H. F., Chen, P. C., Hsieh, W. S., & Hwang, A. W. (2008). The influence of wakeful prone positioning on motor development during the early life. *Journal of Developmental and Behavioral Pediatrics*, *29*(5), 367–376. https://doi.org/10.1097/DBP.0b013e3181856d54

Kurjak, A., Stanojevic, M., Andonotopo, W., Scazzocchio-Duenas, E., Azumendi, G., & Carrera, J. M. (2005). Fetal behavior assessed in all three trimesters of normal pregnancy by four-dimensional ultrasonography. *Croatian Medical Journal*, *46*(5), 772–780.

Learning and memory : a comprehensive reference. (2008) (1st ed. .). Amsterdam : Amsterdam .

Leung, A., Mandrusiak, A., Watter, P., Gavranich, J., & Johnston, L. M. (2017). Impact of Parent Practices of Infant Positioning on Head Orientation Profile and Development of Positional Plagiocephaly in Healthy Term Infants. *Physical and Occupational Therapy in Pediatrics*, *2638*, 1–14. https://doi.org/10.1080/01942638.2017.1287811

Linz, C., Kunz, F., Boehm, H., & Schweitzer, T. (2017). Positional Skull Deformities Etiology, Prevention, Diagnosis, and Treatment. *Deutsches Arzteblatt International*, *114*(31–32), 535+. https://doi.org/10.3238/arztebl.2017.0535

Lobo, M. a, Harbourne, R. T., Dusing, S. C., & Mccoy, S. W. (2013). Grounding Early Intervention :, *93*(1).

Losee, J. E., Mason, A. C., Dudas, J., Hua, L. B., & Mooney, M. P. (2007). Nonsynostotic occipital plagiocephaly: Factors impacting onset, treatment, and outcomes. *Plastic and Reconstructive Surgery*, *119*(6), 1866–1873. https://doi.org/10.1097/01.prs.0000259190.56177.ca

Luca, F. De, & Hinde, A. (2016). Effectiveness of the “ Back-to-Sleep ” campaigns among healthcare professionals in the past 20 years : a systematic review. https://doi.org/10.1136/bmjopen-2016-011435

Martiniuk, A. L. C., Vujovich-Dunn, C., Park, M., Yu, W., & Lucas, B. R. (2017). Plagiocephaly and Developmental Delay: A Systematic Review. *Journal of Developmental and Behavioral Pediatrics*. https://doi.org/10.1097/DBP.0000000000000376

Matsuda, M., Mataki, Y., & Mutsuzaki, H. (2018). Immediate effects of a single session of robot-assisted gait training using Hybrid Assistive Limb (HAL) for cerebral palsy, 207–212.

Me, L., & Heathcock, J. (2005). The Relative Kicking Frequency of Infants Born Full-term and Preterm During Learning and Short-term and Long-term Memory Periods of the Mobile Paradigm. *Physical Therapy*, (June). https://doi.org/10.1093/ptj/85.1.8

Monfort, K., & Case-Smith, J. (1997). The Effects of a Neonatal Positioner on Scapular Rotation. *American Journal of Occupational Therapy*, *51*(5), 378–384. https://doi.org/10.5014/ajot.51.5.378

Newswire, A. P. R., York, N., & York, N. (2008). Lack of Time on Tummy Shown to Hinder Achievement of Developmental Milestones , Say Physical Therapists American Physical Therapy Association Recommendations In Line with National Survey Findings, 1–3.

Nuysink, J., Eijsermans, M. J. C., Van Haastert, I. C., Koopman-Esseboom, C., Helders, P. J. M., De Vries, L. S., & Van Der Net, J. (2013). Clinical course of asymmetric motor performance and deformational plagiocephaly in very preterm infants. *Journal of Pediatrics*, *163*(3), 658–665.e1. https://doi.org/10.1016/j.jpeds.2013.04.015

Ohman, A., Nilsson, S., Lagerkvist, A. L., & Beckung, E. (2009). Are infants with torticollis at risk of a delay in early motor milestones compared with a control group of healthy infants? *Developmental Medicine and Child Neurology*, *51*(7), 545–550. https://doi.org/10.1111/j.1469-8749.2008.03195.x

Pin, T., Eldridge, B., & Galea, M. P. (2007). A review of the effects of sleep position , play position , and equipment use on motor development in infants. *Developmental Medicine and Chil Neurology*, *49*, 858–867.

Reeb-sutherland, B. C., Levitt, P., & Fox, N. A. (2012). The Predictive Nature of Individual Differences in Early Associative Learning and Emerging Social Behavior, *7*(1). https://doi.org/10.1371/journal.pone.0030511

Rogers, E., Polygerinos, P., Walsh, C., & Goldfield, E. (2015). Smart and Connected Actuated Mobile and Sensing Suit to Encourage Motion in Developmentally Delayed Infants [1]. *Journal of Medical Devices*, *9*(3), 30914. https://doi.org/10.1115/1.4030550

Rovee-collier, C. (2016). The Development of Infant Memory CHANGES IN, *8*(3), 80–85.

Rovee-Collier, C. (1987). Learning and memory in infancy. In *Handbook of infant development (2nd ed.). Wiley series on personality processes*.

Rovee-Collier, C. K., & Gekoski, M. J. (1979). The economics of infancy: a review of conjugate reinforcement. *Advances in Child Development and Behavior*, *13*, 195–255.

Rovee-Collier, C. K., Sullivan, M. W., Enright, M., Lucas, D., & Fagen, J. W. (1980). Reactivation of infant memory. *Science*, *208*(4448), 1159–1161. https://doi.org/10.1126/science.7375924

Russell, D. C., Therapy, O., Kriel, H., & Physiotherapy, M. S. (2009). Prone positioning and motor development in the first 6 weeks of life. *Therapy*, *39*(1).

Salls, J. S., Silverman, L. N., & Gatty, C. M. (2000). The Relationship of Infant Sleep and Play Positioning to Motor Milestone Achievement, 577–580.

Sargent, B., Kubo, M., & Fetters, L. (2017). Infant Discovery Learning and Lower Extremity Coordination: Influence of Prematurity. *Physical and Occupational Therapy in Pediatrics*, *2638*, 1–16. https://doi.org/10.1080/01942638.2017.1357065

Sargent, B., Reimann, H., Kubo, M., & Fetters, L. (2015). Quantifying Learning in Young Infants: Tracking Leg Actions During a Discovery-learning Task. *Journal of Visualized Experiments*, (100), e52841. https://doi.org/10.3791/52841

Sargent, B., Scholz, J., Reimann, H., Kubo, M., & Fetters, L. (2015). Infant Behavior and Development Development of infant leg coordination : Exploiting passive torques □, *40*, 108–121.

Sargent, B., Schweighofer, N., Kubo, M., & Fetters, L. (2014a). Infant Exploratory Learning : Influence on Leg Joint Coordination, *9*(3). https://doi.org/10.1371/journal.pone.0091500

Sargent, B., Schweighofer, N., Kubo, M., & Fetters, L. (2014b). Infant exploratory learning: Influence on leg joint coordination. *PLoS ONE*, *9*(3). https://doi.org/10.1371/journal.pone.0091500

Shumway-Cook, A., & Woollacott, M. H. (2007). Motor control : Translating research into clinical practice. In *Motor control : Translating research into clinical practice* (3rd ed., pp. 30–31). Philadelphia: Lippincott Williams & Wilkins.

Speltz, M. L., Collett, B. R., Stott-Miller, M., Starr, J. R., Heike, C., Wolfram-Aduan, A. M., … Cunningham, M. L. (2010). Case-Control Study of Neurodevelopment in Deformational Plagiocephaly. *Pediatrics*, *125*(3), e537–e542. https://doi.org/10.1542/peds.2009-0052

Street, L., Washington, S., Hagen, J. W., & Ph, D. (2008). Society for Research in Child Development. *Child Development*, *58*(3), 829–841.

Tarabulsy, G. M., Tessier, R., & Kappas, A. (1996). Contingency detection and the contingent organization of behavior in interactions: Implications for socioemotional development in infancy. *Psychological Bulletin*, *120*(1), 25–41. https://doi.org/10.1037/0033-2909.120.1.25

Taylor, H. B., Barnes, M. A., Landry, S. H., Swank, P., Fletcher, J. M., & Huang, F. (2013). Motor contingency learning and infants with spina bifida. *Journal of the International Neuropsychological Society*, *19*(2), 206–215. https://doi.org/10.1017/S1355617712001233

Thelen, E. (1995a). Motor development: A new synthesis. *American Psychologist*, *50*(2), 79–95. https://doi.org/10.1037/0003-066X.50.2.79

Thelen, E. (1995b). Motor development. A new synthesis. *The American Psychologist*. https://doi.org/10.1037/0003-066X.50.2.79

Thelen, E. (1998). Bernstein's Legacy for motor development: How infants learn. In *Progress in Motor Control: Bernstein's Traditions in Movement Studies*.

Thelen, E. (2005). Dynamic Systems Theory and the Complexity of Change. *Psychoanalytic Dialogues, 15*(2), 255–283. https://doi.org/10.1080/10481881509348831

Tummy Time -AAP.org. (2018). Retrieved from https://www.aap.org/en-us/about-the-aap/aap-press-room/aap-press-room-media-center/Pages/Tummy-Time.aspx

Turk, A. E., McCarthy, J. G., Thorne, C. H. M., & Wisoff, J. H. (1996). The "Back to Sleep Campaign" and Deformational Plagiocephaly: Is There Cause for Concern? *Journal of Craniofacial Surgery*. https://doi.org/10.1097/00001665-199601000-00006

Vaivre-Douret, L., Ennouri, K., Jrad, I., Garrec, C., & Papiernik, E. (2004). Effect of positioning on the incidence of abnormalities of muscle tone in low-risk, preterm infants. *European Journal of Paediatric Neurology*, *8*(1), 21–34. https://doi.org/10.1016/j.ejpn.2003.10.001

van Vlimmeren, L. A., van der Graaf, Y., Boere-Boonekamp, M. M., L'Hoir, M. P., Helders, P. J. M., & Engelbert, R. H. H. (2007). Risk Factors for Deformational Plagiocephaly at Birth and at 7 Weeks of Age: A Prospective Cohort Study. *Pediatrics*, *119*(2), e408–e418. https://doi.org/10.1542/peds.2006-2012

Watanabe, H., & Taga, G. (2009). Infant Behavior and Development Flexibility in infant actions during arm- and leg-based learning in a mobile paradigm, *32*, 79–90. https://doi.org/10.1016/j.infbeh.2008.10.003

Watanabe, H., & Taga, G. (2011). Initial-state dependency of learning in young infants. *Human Movement Science*, *30*(1), 125–142. https://doi.org/10.1016/j.humov.2010.07.003

Williams, H. (2008). Lumps, bumps and funny shaped heads. *Archives of Disease in Childhood: Education and Practice Edition*, *93*(4), 120–128. https://doi.org/10.1136/adc.2008.145532

Zachry, A. H., & Kitzmann, K. M. (2011a). Caregiver awareness of prone play pecommendations. *American Journal of Occupational Therapy*, *65*(1), 101–105. https://doi.org/10.5014/ajot.2011.09100

Zachry, A. H., & Kitzmann, K. M. (2011b). Caregiver awareness of prone play pecommendations. *American Journal of Occupational Therapy*, *65*(1), 101–105. https://doi.org/10.5014/ajot.2011.0910

Vita

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