ABSTRACT

THE EMERGENCE OF OPEN CUP DRINKING: INFLUENCES OF CUP DESIGN ON HAND AND JAW COORDINATION

by Katherine Elizabeth Frey

The purpose of this study was to systematically analyze open cup drinking development and to identify observable drinking behaviors that allow a child to successfully drink from an open cup. Four subjects were observed three times over a three month period. Subjects drank from four types of cups, each with a unique design feature. Observable drinking behaviors were documented and force applied to the cup when drinking was measured. Study results indicate that universal behaviors exist across subjects. However, unique or individualized behavior patterns exist within the range of typical development. In addition, results showed that cup features influence sensory motor skills when drinking. Finally, pressure results indicated that force applied either decreased or became more consistent as fine motor skills improved. Future research is needed to examine open cup drinking patterns and the impact of cup design on cup drinking skills among a larger subject population.
THE EMERGENCE OF OPEN CUP DRINKING: INFLUENCES OF CUP DESIGN ON HAND AND JAW COORDINATION

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Uncertainty exists as to what physiologic event(s) occur that allow a child to successfully drink from an open cup independently. Clinicians have noted through general observation that successful open cup drinking is associated with certain skills. Anecdotal evidence reports signs of readiness as: coordination between the hand and jaw, head and trunk stabilization, controlled grading of the jaw, lip closure and volitional control of the tongue (Rogers & Arvedson, 2005). However, the noted associations are general parameters to help clinicians identify signs of readiness for open cup drinking with no formal research studies having been conducted. Therefore the purpose of the study includes: 1) Provide a detailed analysis of open cup drinking development and identify observable drinking behaviors which allow a child to successfully drinking from an open cup over a three month period; and, 2) identify change(s) that occur during the transition from early to middle stages of open cup drinking development (Table 9). These components are essential for understanding the progression from bottle to open cup drinking.

Typically developing children, around 6 months of age, begin transitioning from reflexes to volitional motor control which allows feeding and drinking skills to advance. Feeding skills that emerge as a direct result of matured motor function include: tongue lateralization, rotary chewing, spoon feeding, management of advancing food textures, and self-feeding. A number of drinking skills also emerge as motor skills advance including: development of a mature suck, anterior lip seal, jaw grading, and hand to mouth movements. In addition, more coordinated and stabilized movements of the head, neck, jaw, lips and tongue enable a child to transition from a bottle to open cup drinking. Open cup drinking has been documented to develop between 10 and 24 months of age within clinical settings (Alexander, 1987). In order to fully understand the complex intricacies involved during the transition from bottle to early open cup drinking, physiologic
development and milestones beginning in utero through the early postnatal months must be examined.

For the reader to better understand the developmental process, some basic terminology must be defined. Gestational age (GA) is the time between the first day of the last menstrual period and the day of delivery (American Academy of Pediatrics, 2004). The first day of the last menstrual period occurs roughly 2 weeks prior to ovulation and 3 weeks before implantation of the blastocyst. Traditionally, GA is expressed in weeks and is used to estimate the delivery or birth date. As an infant develops post birth, age is no longer defined by gestational age. In contrast, the term chronological age (CA) is used to describe elapsed time after birth (American Academy of Pediatrics, 2004). Chronological age may be measured in days, weeks, months or years. Chronological age and GA should not be confused or compared with other terms such as conceptional age or postmenstrual age (American Academy of Pediatrics).

Prenatal Development

Embryonic Period

Milestones in uterine development, particularly of the head, neck and orofacial region are significant to successful feeding and cup drinking. Between three to six weeks GA, all major organ systems begin to develop (Delaney & Arvedson, 2008). The head and neck form and primitive facial structures emerge. Cartilage and membranous neurocranioum create the skull base and cranial vault (Holzman, 1998). Skull shape influences the formation and growth of the pharynx, the face and palate (Holzman, 1998; Larson, 1993). Central nervous system structures including the neural plate, neural tube, forebrain, midbrain and hindbrain also emerge during these early weeks (Larson, 1993).

The laryngeal component of the aerodigestive tract begins developing early in the embryonic stage of development, and begins with the formation of the laryngotracheal groove. The laryngotracheal groove forms a tube that connects the trachea and larynx (Harjeet, Sahni, & Jit, 2004). As development continues, separation of the laryngotracheal tube divides the larynx and trachea into individual structures (Adewale, 2009). The laryngotracheal tube grows caudally into the anterior surface of the foregut, separating the
left and right lung buds. Simultaneous with the forming larynx and trachea, the pharynx emerges superiorly. The larynx, located between the pharynx and trachea, is positioned more superiorly in infants than adults (Adewale, 2009).

A defined larynx can be identified around 41 days GA (Adewale, 2009; Holzman, 1998). The larynx is formed by cartilages, ligaments and muscles including the cricoid cartilage, paired arytenoids, the epiglottis and paired cuneiform cartilages. These structures create the framework of the larynx. Cartilages within the framework articulate with the muscles of the larynx. The thyroid cartilage is the largest of the cartilages and forms the anterior laryngeal prominence (Adewale, 2009). Below the thyroid is a signet shaped ring called the cricoid cartilage which is the only complete ring of the respiratory tract. Both the thyroid and cricoid cartilages begin transitioning from tissue to cartilages around 7 weeks GA (Adewale; Holzman, 1998). The paired arytenoid cartilages are located on the superior-posterior potion of the cricoid cartilage. Connected to the anterior aspect of the arytenoid is the vocal process in which the vocal ligament attaches (Adewale). At the apex of the arytenoids are the corniculate cartilages which aid in medial movement. The true vocal folds and glottis are formed by several membranous layers. A primitive glottis is formed around 10 weeks GA when the true vocal folds separate (Adewale; Holzman). The vestibular or false folds located superiorly to the true vocal folds, are formed by mucosa that covers the thyroartenoid muscles. Both the true and false vocal folds are structures that provide airway protection during feeding and swallowing.

Separation of the laryngotracheal tube also causes the larynx to divide further into individual structures (Adewale, 2009). The epiglottis, which develops from the third and fourth brachial arches, is formed from the primitive laryngeal cartilages (Holzman, 1998). In utero and infancy, the epiglottis is narrow, flexible and positioned horizontally in relation to the trachea. The shape is similar to a “v” and is commonly furrowed. The epiglottis attaches to the posterior portion of the larynx and provides airway protection during swallowing (Adewale, 2009). As an infant matures, the epiglottis provides less airway protection and becomes firm, broad and parallel to the trachea (Adewale). The laryngotracheal groove also forms the trachea, which extends inferiorly from the larynx and anterior of the esophagus (Harjeet et al., 2004; Holzman, 1998). During development, the laryngotracheal tube grows faster than the esophagus. Tracheal growth
is commonly followed by examining tube diameter (Holzman). Early in utero, tracheal width is 4.3 mm and endodermal pouches separate the pharynx and esophagus transforming the groove into the laryngotracheal tube (Harjeet et al., 2004). The laryngotracheal tube forms the rostral portion of the larynx and the caudal portion forms the trachea. The caudal portion of the tube forms the trachea and bifurcates forming the primary bronchi (Harjeet et al.). When the diameter of the trachea reaches 22 mm, the epiglottis and thyroid cartilages are well defined with more definition of trachea apparent rostrally than caudally. At 30 mm in diameter, incomplete tracheal rings become cartilaginous and are well defined. As diameter continues to increase, the epiglottis and thyroid cartilage continue to develop and all layers of the tracheal wall are apparent (Harjeet et al.). In addition, the trachealis muscle emerges and is seen in intervals between the tracheal rings. Tracheal diameter continues to increase throughout development as muscular layers and the tracheal structure become more defined (Harjeet et al.). During bifurcation of the trachea, pathways are formed down to the developing lungs. The respiratory component of the aerodigestive tract also begins developing early in utero. Fetal lung development is often described in phases of embryonal, pseudoglandular, canlicalar, saccular and alveolar development (Kasprian, Balassy, Brugger, & Prayer, 2006; Hislop, 2005). Developmental phases are used for organizational purposes and transition fluently from one to the next.

**Embryonal Phase**

In the embryonal phase (up to 7 weeks GA) two buds emerge from the ventrolateral wall of the foregut and two main bronchi form as a result of bifurcation of the inferior portion of the trachea. Accompanying early lung development is blood circulation (Hislop, 2005). Capillary networks begin surrounding the primitive airway around 34 weeks GA. Molecular interactions between epithelial lung components initiate branching morphogenesis and bronchial budding (Kasprian et al., 2006). Elongation of the bronchi occurs simultaneously with development of pulmonary vasculature. The pulmonary circulatory system emerges by 5 weeks GA and bronchial arteries arise from the aorta of the heart around 8 weeks GA (Hislop, 2005).
**Pseudoglandular Phase**

Bronchial branching is followed by the pseudoglandular phase of development as the lungs are tubular structures with little differentiation in membrane lining. Mucus glands, bronchial cartilage and epithelial airways cells are established around 10-12 weeks GA (Kasprian et al., 2006). Also during the pseudoglandular phase, bronchial branching exponentially increases. About three-fourths of all bronchial branching occurs between 10 and 14 weeks GA (Kasprian et al., 2006).

**Canalicular Phase**

The canalicular phase (17-20 weeks GA) initiates as the lumina or the airway widens. In addition, the epithelium responsible for gas-exchanges flattens and distal pulmonary vasculature begins rapid expansion (Hislop, 2005). Peripheral airways enlarge and the epithelium lining begins to form type I and II pneumonocytes (Hislop, 2005). During the canalicular phase mechanical forces are highly influential on lung development. Transpulmonary pressure and cyclic stretch are both mechanical forces placed on the lungs that are generated by permanent secretion of lung fluid and fetal breathing movements (Kasprian et al., 2006). Throughout development the lungs secret liquid that is essential for normal lung development and contributes amniotic fluid volume and electrolyte balances (McCray, Bettencourt, & Bastacky, 1992). Lung fluid also affects the shape and formation of the developing alveoli and airways. The liquid is cleared from the lungs by fetal breathing movements and phasic peristaltic contractions of the airway generated by bronchial smooth muscles (McCray et al., 1992). About 50% of the lung liquid contributes to 30% of amniotic fluid volume. The other 50% is swallowed by the fetus (Kasprian et al., 2006). Between weeks 13-26 GA, fewer breathing movements occur. During periods of breathing apnea, high laryngeal and transpulmonary pressures prevent lung liquid from escaping which keep the lungs in an expanded state (Kasprian et al.). Transpulmonary pressure also aids in alveolar growth, preparing tissues for gas-exchange. Alveocysts react to mechanical influences by production of surfactant. When surfactant is produced biochemical events occur which thin the future blood-air barrier (Kasprian et al.).
**Saccular Phase**

Between 24 and 26 months GA, lung tissue development reaches the saccular phase allowing infants to survive with intensive neonatal care. However, biochemical lung maturation is still in early stages. Type II alveolar cells begin to produce surfactant (Kasprian et al., 2006). Surfactant is a substance made of phospholipids and proteins and is detectable in most fetuses around 30 weeks GA (Kasprian et al., 2006). As surfactant is produced, the amount of gas exchange surfaces and alveoli dramatically increase. By approximately 26-29 weeks GA, the lungs are capable of breathing air which is a critical milestone for infants born pre-term (Kasprian et al.; Hislop, 2005). However until birth the child receives oxygen via the mother’s supply of oxygenated blood.

**Alveolar Phase**

The majority of alveoli are formed during the alveolar phase which begins around 36 weeks GA (Hislop, 2005). During the postnatal period, alveoli multiply and continually increase in size and number until somatic cell growth is complete, around 2-4 years CA (Hislop, 2005). Postnatally the respiratory mechanism relies on coordinated breathing movements as well as neural output from a central pattern generator to efficiently oxygenate the body (Barlow, 2009). Coordination of respiration is monitored by peripheral and central chemosensors and bronchopulmonary vagal afferent nerves (Frappell & MacFarlane, 2005). Efficient ventilation also relies on mechanical properties of the respiratory system. Together, the lungs, airways and chest wall coordinate and move during gas exchange (Barlow, 2009). After birth, respiration must coordinate with many activities including feeding and swallowing to ensure successful feedings and the ingestion of adequate nutrition. Due to the complex development of the aerodigestive tract, infants born before 34 weeks GA are at significant risk for respiratory as well as feeding and swallowing disorders in early infancy (Rogers & Arvedson, 2005). The interaction of respiration and swallowing will be discussed later.

**Upper Gastrointestinal Development**

In addition to the respiratory system, the esophagus and upper gastrointestinal tract begin developing around 3 weeks GA. The esophagus becomes a patent tube and
develops circular and longitudinal muscles between 10-12 weeks GA (Malinger, Levine, & Rotmensch, 2004). As swallowing emerges as early as 15 weeks GA, coordinated esophageal responses from the pharynx to the stomach emerge. Coordinated movements indicate central nerve control and peripheral sensory feedback is provided to the oropharyngeal region (Malinger et al., 2004). Swallowing amniotic fluid aids in development of the upper gastrointestinal track and initiates gastric emptying. Esophageal motility and opening of the fetal lumen is observed. Fetal hiccups or regurgitation also initiates the esophageal response (Malinger et al.). Despite early signs of motility, a well-developed esophagus with upper esophageal sphincter tone and coordinated lower esophageal sphincter relaxation does not occur consistently until 32 weeks GA (Jadcherla & Shaker, 2000). Even term newborns experience uncoordinated esophageal response to swallowing which is evident by a rapid rate of peristalsis, biphasic peristaltic waves and simultaneous contractions of the entire esophagus (Malinger et al.). Although full term infants are born ready to digest human milk, motor function of the gut is less advanced at birth compared to older children (Jadcherla & Shaker, 2000). About half of all newborns regurgitate suggesting that the esophagus and upper digestive tract take time adjusting to new environmental conditions. Development of the upper GI tract and digestion is also influenced by factors including nutrient content during feedings and the presence of any related diseases (Jadcherla & Shaker).

**Development of oral behaviors and movement patterns**

As systems related to feeding and swallowing develop, differentiation of tissues of other organ systems occurs throughout the body. Approximately 3-4 weeks GA, neural crest cells migrate to brachial arch mesoderm (Holzman, 1998). Cell migration and interaction with differentiating cells result in the development of the face. A primitive mouth or stomodeum, a slight depression in the surface of ectoderm, begins developing from the first brachial arch (Holzman, 1998). Mandibular prominences grow medially and merge with together by the end of the 4th week GA, forming the lower lip, chin and mandible (Holzman). The upper lip is formed by maxillary and medial prominences. Around 12 weeks GA, fusion between the hard and soft palate and between the nasal septum and palatine process occurs (Adewale, 2009). The tongue also begins forming from
multiple brachial arches, hence its complex innervation of sensory and motor nerves (Holzman). Facial and oral structures including the lips, tongue and jaw can be adequately identified by 4D ultrasound at 15 weeks gestational age (Miller, Sonies, & Macedonia, 2003). Each structure largely impacts feeding and the development of open cup drinking; therefore typical development of orofacial structures is critical. In utero, structures including the lips, tongue and jaw begin moving and working as one unit. Movement is generalized to the entire orofacial area (Meyer, 2000; Morris, 1985; Herring, 1985).

Facial and oral development is complex and composed of numerous muscles that are necessary for many activities, including cup drinking (Table 6). The basic form or shape of the face is created between 4-10 weeks GA (Holzman, 1998). The second pharyngeal arch gives rise to the muscles of facial expression (Larson, 2003). The lips create the orifice of the mouth formed by muscle and mucous membrane. Underlying musculature of the lips is the orbicularis oris (OO), a complex network of muscle fibers which is an insertion point for many muscles of facial expression (Blair, 1986). The orbicularis oris is not a sphincter muscle, rather two distinct muscles that are defined as superior (OOS) and inferior (OOI) portions. The superior and inferior OO muscle fibers run parallel to the vermilion boarder and integrate into several different classes of muscle fibers (Blair, 1986). Complex integration of muscle fibers as well as insertion into the epidermal regions superior and inferior to the vermilion suggest that the OO is capable of precise and articulate movement under refined neural control (Blair). The buccinator, which blends with the superior and inferior OO is the primary muscle of the cheek. Contraction of the buccinator causes the lips and cheeks to compress against the teeth and draws the corners of the mouth laterally, a necessary movement during cup drinking. The risorius runs parallel and superficial to the buccinator muscle. Fibers of the risorius muscle insert into the skin and mucosa at the corner of the OOI and OOS (Blair). Contraction of the risorius draws the corners of the OO laterally. The levator labii superioris and zygomatic major insert into the OOS. The muscles of facial expression receive motor innervation from branches of the facial nerve (CN VII). The face and facial muscles receive sensory information from the trigeminal nerve (CN V) (Zemlin, 1998).

The tongue is also identified at approximately 15 weeks GA. The structure is large and rests at the floor of the mouth. Functions of the tongue include taste, mastication,
deglutition, and speech production. The tongue is considered one of the most important and active articulators (Zemlin, 1998) and is critical for cup drinking. Muscles of the tongue develop from the first, third and fourth pharyngeal arches in early utero. The first and third arches form the anterior two thirds and the fourth arch creates the posterior third of the tongue (Holzman, 1998; Larson, 1993). Muscles of the tongue are regularly divided into intrinsic and extrinsic depending of their origin (Table 7). The extrinsic muscles are typically considered gross movers that shift the tongue in a general direction. Intrinsic muscles make fine or refined movements of tongue placement. Both the extrinsic and intrinsic tongue muscles receive motor innervation from the hypoglossal nerve with the exception of the palatoglossus which receives motor innervation from the pharyngeal branch of the vagus nerve (Larson, 1993). General sensory receptors of the anterior two-thirds of the tongue are supplied by the trigeminal nerve (CN V). In addition to general sensation, the tongue surface is covered with tastes buds. Taste buds on the anterior two-thirds of the tongue are supplied by the facial nerve (CN VII) (Larson). The general sensory and taste receptors of the posterior one-third of the tongue are both supplied by the glossopharyngeal nerve. The small area on the most posterior portion of the tongue, which derives from the fourth pharyngeal arch, receives sensory innervation from the superior laryngeal branch of the vagus nerve (Larson).

Three types of lingual movement patterns have been recorded via ultrasound as early as 15-18 weeks GA (Miller et al., 2003). The first movement consists of a forward thrust of the tongue to the lower labial margin which emerges between 15 and 21 weeks GA. The second emerging lingual movement pattern is tongue cupping which has been observed in conjunction with anterior thrust patterns as early as 16 weeks GA (Miller et al., 2003). Tongue cupping is the formation of a depression or cupping of the tongue midline along the dorsum of the tongue. Tongue cupping in utero appears similar to postnatal cupping of the tongue around a nipple in newborn infants or to an adult holding a bolus on the tongue before swallowing (Miller et al.). A third tongue movement pattern emerges as early as 18 weeks GA. The third movement pattern is described as an anterior protrusion of the tongue that extends beyond the labial boundaries followed by posterior retraction (Miller et al.). Ultimately, the anterior-posterior protrusive lingual movements of this third type of tongue pattern will be paired with anterior thrusts and cupping, observed in term
infants postnatally (Arvedson, Rogers, & Brodsky, 1993). Around 28 weeks GA, lingual movements become more frequent. Tongue cupping movement patterns and anterior-posterior movements are observed consistently (Miller et al.).

Another critical oral structure that is evident by 15 weeks via ultrasound is the mandible, which contributes to speech production, chewing, biting swallowing, and grading for open cup drinking (Yamane & Fukui, 2007). Early mandibular movements have recently been observed around 16 weeks GA using 4-D ultrasound (Miller et al., 2003). These early mandibular movements are observed as groups of 5-14 small jaw openings with the initial mouth position being slightly open. Over time, a more definite non-repetitive opening and closing of the jaw may be observed (Miller et al., 2003). Early oral movements are essential for continuing development of the mandible (Herring, 1985).

The muscles of mastication derive from the first pharyngeal arch and can be grouped on a functional basis into mandibular elevators and depressors (Table 7) (Larson, 2003). Mandibular elevators include the masseter, temporalis and medial pterygoids. Protrusion of the mandible is controlled by the lateral pterygoid. The mandible is depressed by the digastricus, mylohyoid and geniohyoid (Zemlin, 1998). The muscles of mastication receive motor innervated from the trigeminal cranial nerve with the exception of the geniohyoid, which receives motor innervation from the hypoglossal cranial nerve (Larson, 2003). Sensory aspects of mastication and neuromuscular control will be discussed later.

Around 15 weeks GA, the pharyngeal swallow or true bolus swallow has also been observed to emerge (Miller et al., 2003). However, consistent swallowing observations in utero does not appear until 22-24 weeks GA, with the most active period of swallowing amniotic fluid occurring between 17-30 weeks GA (Miller et al., 2003). During this period of intrauterine swallowing, oral and nasopharyngeal closure during the swallow does not yet occur. Instead, inhalatory-like movements and anterior-posterior suckling-like movements are used to gather or collect a bolus. Many fetuses approximate their lips once a bolus is collected, however lip closure is not a prerequisite to swallow. Tongue cupping holds the bolus in the oral cavity prior to posterior elevation of the velum. The soft palate and dorsum of the tongue approximate during collection of the bolus (Miller et al.). During the swallow, peristaltic tongue movements occur to propel the bolus posteriorly (Scarborough, Miller & Fletcher, 2008).
Oral-facial stimulation such as finger sucking or hand stroking the cheek begins around the same time anterior-posterior lingual movements appear (as early as 18 weeks GA). Stimulation of the orofacial region has been observed to increase the tongue movement response (Miller et al., 2003). Around 20 weeks GA, early tongue movements transition into a suckle reflex tongue movement pattern. Suckling is a movement pattern in which the tongue extends and retracts. The extension and retraction movement is a rhythmic cycle (Meyer, 2000). Typically, jaw opening and closing corresponds with the tongue movement (Morris, 1985). The lips remain loose with a reduced seal and wide mandibular excursions. The suckle is present in healthy babies from 20 weeks GA to approximately six months of age. After 28 weeks GA, lingual movements including those involved with suckling become increasingly complex. The suckling reflex matures with gestational age; particularly weeks 34 through 37 and are critical for feeding skill refinement (Gewolb & Vice, 2006). Postnatally, after six months (CA), a more mature suck and tongue pattern develops and will be discussed later.

Suckling and lingual movements in utero are also linked to pre-swallowing stimulation behaviors. Such stimulation behaviors include hand contact to the head or face, hand contact to mouth (suckling digits and hands), or mouth contact to other extremities including the umbilical cord or placenta (Miller et al., 2003). Hand to mouth and other mouthing movements during utero are an important part of oral development and have been suggested as a precursor of successful feeding after birth (Case-Smith, Cooper, & Scala, 1989).

Gender related differences in the developmental course of select oropharyngeal structures and movement patterns observed via 4-D ultrasound have been documented (Miller, Macedonia, & Sonies, 2006). Ultrasound images revealed that development in lingual and pharyngeal structures, motor activities and oral-motor skills emerged earlier in females than in males. In addition, pharyngeal and laryngeal movement in males was less consistent compared to females during the second trimester. By the third trimester, movement patterns became similar. Overall, oral motor skills were attained earlier by females in utero, which may suggest gender-related development patterns for motor development of oral musculature (Miller et al., 2006).
In addition to the suckle reflex, other primitive reflexes involved with ingestion or airway protection begin to emerge around 26 weeks GA. The gag reflex is a protective mechanism for infants (Leder, 1996). The gag reflex is considered a “simple” (i.e. short latency) reflex that protects the pharynx from unwanted material (Miller, 2002) and persists throughout adulthood. The gag reflex does not correlate to swallowing ability (Leder, 1996), but is readily used during a neurologic examination to test the glossopharyngeal and vagus nerve stability. The gag can be elicited by stimulation of the posterior tongue, pharyngeal wall, and/or velar regions. The reflex is illustrated by a forward downward movement of the mandible and contraction of the pharyngeal region (Leder). Some recent evidence has shown that more anterior regions of the oropharyngeal cavities, mediated by the trigeminal nerve, in neurologically intact individuals may be involved with the afferent limb of the gag reflex (Scarborough, Bailey Van Kuren, and Hughes, 2008). In typical neonates, the gag may be elicited by non-oral stimulation such as touch to the face or trunk because neonates respond to sensory input by generalized autonomic reactivity (Scarborough, Boyce, McCain, Oppenheimer, August & Strinjas, 2006). Infants may also be startled or experience a behavior state change, transitioning from calm to inconsolable crying, as a result of touch. Observed hypersensitivity is thought to result from poor organization of the autonomic nervous system (Pickler, 2004). After maturation of the ANS occurs, a more typical response to multiple types of touch develops (Scarborough et al., 2006).

The ANS involves self-regulation and organization of respiratory rate and heart rhythm. Between 26-29 weeks GA the nervous systems mature as rhythmic breathing emerges and body temperature is also controlled (Larson, 2003; Rogers & Arvedson, 2005). Control of autonomic functioning is critical for successful bottle or breast feeding, and later open cup drinking (Pickler, 2004). In neurologically immature infants, feeding stresses the nervous system and causes poor or disorganized feeds. Bottle or breast feeding is the most highly organized behavior of a young infant involving coordination of sucking, swallowing and breathing (Pickler, 2004). The ability to maintain autonomic, motor and behavioral state organization during and after feeding signifies an efficient bottle or breast feeder (Pickler). Motor organization is linked to autonomic organization by observable behaviors. Behaviors that signify self-regulation and indicate feeding
readiness include hand-to-mouth activity, hiccups, rooting and fussiness without crying. In addition, a quiet and alert behavior state prior to feeding has been linked greater feeding efficiency (Pickler). Pre-feeding non-nutritive suckling has been documented to facilitate an ideal quite and alert behavior state (Pickler). If the ANS does not mature typically or does not reach an organized behavior state, feeding will be negatively impacted. An infant or child may develop a touch intolerance in which the infant or child reject the oral sensation of food (Scarborough et al., 2006). Dramatic behavior state changes will also result which include an inconsolable cry or gagging.

Other oral motor reflexes including the phasic bite and the transverse tongue response correlate with early feeding skills (Rogers & Arvedson, 2005; Sheppard & Mysac, 1984). The phasic bite develops around 28 weeks GA and has both the sensory and motor components mediated via the trigeminal cranial nerve. The phasic bite is stimulated by touch to the gums and is a precursor to mastication (Sheppard & Mysac, 1984). The reflex diminishes between 9-12 months of age as volitional control replaces the reflex response. Around 28 weeks GA, the transverse tongue reflex emerges and is elicited by stroking the lateral surface of the tongue (Rogers & Arvedson, 2005). The sensory component of the transverse tongue reflex is mediated by the trigeminal nerve and motor portion of the reflex is controlled by the hypoglossal cranial nerve. As a response to stimulation, the tongue moves towards the side of stimulation (Sheppard & Mysac). To an infant, the response has little functional significance, however the movement is a precursor to tongue lateralization utilized in chewing that will emerge at a volitional level (Sheppard & Mysac; Rogers & Arvedson). The reflex diminishes by 6 months of age as volitional control replaces the reflexive response. Automatic reflexes create the foundation for similar movement patterns used during feeding that will emerge under voluntary control (Rogers & Arvedson).

In summary, oral behaviors and movement patterns that develop in utero become more complex and integrated throughout gestation. Jaw and lip movements begin as simple opening movements and later develop into repetitive open-close movements comparable to excursion patterns in infant suckling (Herring, 1985). Lingual movements begin as simple forward thrusting and increase in complexity to cupping and anterior-posterior movements which are also observed in suckling (Case-Smith et al., 1989). Oral
movements in utero are significant to oral development after birth. The amount of jaw, tongue and lip movement during development differentiates efficient from inefficient eaters after birth (Case-Smith et al., 1989).

Postnatal Development

In addition to exploring milestones in utero, physiologic development after birth must also be examined to fully understand the transition from bottle to open cup drinking. Newborn infants integrate new demands and information to achieve stability in their environment. New demands include: stabilization of physiological parameters such as heart rate, breathing, oxygenation and digestion (Pickler, 2004; Ross & Browne, 2002). Pulmonary and vascular resistance increases outside of utero as a result of switching from a fluid to air medium and requires reorganization of endothelial and smooth muscles cells (Hislop, 2005). Oral feeding is another critical demand introduced to infants at birth that requires coordination of oral movements, respiration and deglutition.

Oral structures in a newborn are facilitative for nipple and bottle feeding in the first half year of life due to several unique characteristics (Stevenson & Allaire, 1991). A newborn’s oral structures are similar to an adult, but have some critical proportionality differences. The tongue, soft palate and arytenoid mass are relatively larger compared to their surroundings than in an adult (Stevenson & Allaire, 1991). The hard palate is short and broad with a small arch that contains 5-6 folds which aid in suckling and nipple hold. The tongue fills the oral cavity and makes contact with the gums and roof of mouth, reducing the size of the oral cavity (Delaney & Arvedson 2008; Stevenson & Allaire). Adipose tissue along the masseter muscle fills both lateral sulci, also decreasing intraoral space (Stevenson & Allaire). Less intraoral space allows for generation of stronger suckle pressures. The larynx is positioned higher in infants than adults causing the epiglottis and soft palate to be in close approximation which maximally protects the airway by diverting liquid laterally around the laryngeal opening (Stevenson & Allaire).

Early Feeding

The suckle reflex, as stated previously, emerges around 18 weeks GA and may be characterized as a tongue movement pattern in which the tongue extends and retracts
The suckle is present in healthy neonates to approximately six months CA when a more mature suck emerges. Suckling for nutrition and suckling for non-nutrition are both important early oral motor and sensory experiences (Scarborough et al., 2008; Delaney & Arvedson, 2008). A healthy child uses non-nutritive suckling (NNS) on an object or body part to aid in self-calming and state regulating. Additional benefits of NNS include improved oxygen saturation levels, feeding skills and gastric emptying (Scarborough et al., 2008; Miller, & Kang, 2007). NNS requires less coordination between suck, swallow and respiratory effort compared to the NS (Medoff-Cooper, 2005). NNS is faster and continuous rather than an alternation of bursts and rest periods. Approximately two cycles of a non-nutritive suck-swallow sequence occur per second (Medoff-Cooper, 2005). During NNS, breathing occurs simultaneously while the child suckles 6-8 times before pausing to swallow. NNS is continuous, being interrupted only by the swallow (Medoff-Cooper).

A healthy child uses nutritive suckling (NS) to extract liquid from a nipple or bottle. During NS, an anterior seal is formed around the nipple by the tongue and lower lip (Meyer, 2000). Fat pads in the buccal region support a lateral seal and help secure the nipple in the mouth. The tensor veli palatini of the soft palate and tongue root create a posterior seal which aids in generation of intraoral pressure and protects liquid from entering the pharynx prematurely (Meyer, 2000). The suckle reflex begins as the mandible and front of tongue raise upward and forward as a unit, placing pressure on the base of the nipple. The upward-forward movement creates positive pressure within the oral cavity (Medoff-Cooper, 2005). Next, the jaw and tongue depress and move backward in a unified movement, creating a negative pressure within the oral cavity. Although the tongue moves forward during a suckle, the backwards movement is more pronounced (Medoff-Cooper, 2005). The rhythmical upward-forward and downward-backward stripping action of the tongue allows for extraction of milk out of the nipple and into the mouth (Medoff-Cooper). Movements are similar for breast-feeding and bottle-feeding. Movement of oral structures including the tongue, lips and jaw are interconnected during suckling feeding (Miller & Kang, 2007; Pickler, 2004; Meyer; Morris, 1985). The tongue and jaw work as a unit, rising together to press the nipple against the alveolar ridge and depressing as a unit to create negative pressure within the oral cavity. Correlations have been found between jaw
motion, tongue movement and suction pressures (Meyer). Ultrasound findings suggest that depression and elevation of the jaw assists in dynamic tongue movements in early feeding (Meyer). Moreover, significant associations between tongue movements and the activation of surrounding peri-oral muscles exist during nutritive suckling (Tamura, Horikawa & Yoshida, 1996). Suckling is only one component of the suck-swallow-breathe triad.

Coordination of sucking, swallowing and breathing is essential for safe oral feeding and matures with increasing chronological age (Gewolb & Vice, 2006; Ross & Browne, 2002; Lau & Hurst, 1999). To be an efficient feeder outside the womb, an infant must coordinate sucking, swallowing and breathing in addition to maintaining autonomic, motor, and behavioral state organization (Pickler, 2004). The ability to integrate muscular activity of the lips, tongue and mandible is one crucial component of the triad (Delaney & Arvedson, 2008; Miller & Kang, 2007). Other coordinated motor sequences must also occur aside from the suckle including swallowing and respiration. Precise timing of all muscle activity is a key to successful feeding (Gewolb & Vice, 2006; Pickler, 2004). Coordination of the suck, swallow and breathing rhythm may be predictive of feeding, respiratory or neurodevelopmental defects (Gewolb & Vice).

The suck-swallow-breathe triad is a complex sequence of events that requires enormous coordination of at least 26 muscles while simultaneously processing and responding to neural information. Coordinating muscles of feeding and respiration include the trigeminal, facial, glossopharyngeal, vagus and hypoglossal nerves, and spinal cord segments (Barlow, 2009). Specific focus is placed on the coordination of the facial, tongue, pharyngeal and palatal muscles (Lau & Hurst, 1999). After milk is extracted from a nipple during feeding, tongue and facial muscles contain and control the bolus within the oral cavity in preparation for swallowing (Medoff-Cooper, 2005). The bolus is propelled posteriorly and stimulation of chemoreceptors in the pharynx triggers the swallow. During the swallow, deglutition apnea or the cessation of breathing occurs to protect the airway (Ross & Browne, 2002). Respiratory rates in neonates range from 40-60 breaths per minute. Interruption of airflow during a swallow lasts between 0.35-0.7 seconds, making coordination of the swallow between breaths critical (Lau & Hurst, 1999). The normal NS rhythm is one cycle per second coordinating sucking, swallowing and breathing on a 1:1:1 or 2:2:1 ratio. However, the rate of the suck-swallow-breathe triad is dependent mainly
upon the flow rate of the nipple or spout (Matthew, 1991). During NS, 20-30 suck-swallow-breathe cycles occur preceding a five second break for additional breaths. Stabilization of the suck-swallow-breathe occurs around 36 weeks GA, however coordination of respiration and swallowing occurs later (Gewolb & Vice, 2006).

Additional infantile reflexes, such as the Babkin and grasp reflexes, emerge at birth and are also significant to feeding and drinking development (Sheppard & Mysac, 1984). The Babkin reflex, elicited by placing deep pressure into an infant’s palm, is a precursor to latter developing hand to mouth self-feeding skills. The response to palm pressure includes bringing the hand to face, the mouth opens, eyes close and the head is tilted forward (Sheppard & Mysac, 1984). The Babkin reflex creates the foundation for a similar response that will emerge on a volitional level during self-feeding (Sheppard & Mysac). The reflex diminishes around 3 months CA during the time infants begin to volitionally reach for objects. In addition to the Babkin reflex, the grasp reflex is also present at birth. Touch to the medial plane of a child’s fingers elicits a grasping response, which is a precursor for finger feeding and holding a cup, spoon or bottle. The grasp reflex creates a foundation for feeding skills that will develop on a volitional level (von Hofsten, 1982). The grasp reflex diminishes around 2 months of age, as volitional control of the grasp emerges between 2-4 months CA. Around the same time volitional grasping emerges, forward arm extensions that are volitionally directed toward objects or food is observed. These “pre-reaching” behaviors correspond with grasping and early self-feeding skills. Pre-reaching is typically paired with openings of the hand and extension of the fingers (von Hofsten, 1982). Between 4-5 months CA, a transition period occurs from pre-reaching to a more advanced visually guided or goal-directed reaching. Visually guided reaching involves coordinated and combined reaching and some grasping activity (von Hofsten & Lindhagen, 1979). Around 6 months CA, consistent, volitional grasping behaviors should be observed.

Emergence of Voluntary Control

The transition from reflexes to voluntary control for most oropharyngeal skills also begins around 6 months CA (Rogers & Arvedson, 2005). During the transition to volitional control, the tongue, lips and jaw begin working as separate entities and disassociate from one another (Bosma, 1985; Stolovitz & Gisel, 1991). Anatomical changes occur that
transform an infant’s oral mechanism to be more adult-like (Stevenson & Allaire, 1991). Significant changes include: the hyoid and larynx grow downward; the cricoid cartilage lowers from opposite of the fourth cervical vertebra at birth to the level of the fifth cervical vertebra at 6 years of age (Adewale, 2009); a greater separation exists between the epiglottis and larynx; reduction of buccal adipose tissue; and elongation of the oral cavity. With neurologic maturation and improved feeding coordination, infants do not require as much anatomical support and airway protection (Stevenson & Allaire, 1991).

   During the time anatomical changes occur, the transition from an early suckle pattern to a more mature suck emerges which is the primary tongue movement pattern in adults. Unlike the suckle, the suck is under volitional control and has a cyclical up-down movement in which the tongue remains in the mouth. Tongue is flat and thin as the tip rises to the anterior palate (Delaney & Arvedson, 2008). The lips form a tight seal with reduced tongue seal and mandibular excursions, which is optimal for open cup drinking. The mature suck has longer sucking bursts and larger volume intake per suck as compared to the suckle (Delaney & Arvedson, 2008). An increase intraoral space allows for greater tongue mobility (Delaney & Arvedson, 2008; Stevenson & Allaire, 1991) and facilitates greater pressure generation allowing for more efficient feeding (Logan & Bosma, 1967; Matthew, 1991). Positive pressure is created when the jaw elevates, the tongue elevates to the hard palate and the lips seal. Negative pressure is created when the jaw drops, the tongue moves away from the hard palate, the posterior buccal muscles contract, the soft palate elevates and the lips remained sealed (Arvedson et al., 1993).

**Transitional Feeding Phase**

   Between 4-6 months CA, a transitional feeding phase occurs that appears to be a result of the anatomic and physiologic changes (Stolovitz & Gisel, 1991; Bosma, 1986; Delaney & Arvedson, 2008). The transitional feeding phase begins as pureed vegetables, fruits and rice cereal are introduced by spoon. By the transitional period, an infant’s digestive system has matured enough to tolerate food other than milk (Malinger et al., 2004). In addition, gains in gross and fine motor skills allow the child support their head and trunk while in a sitting posture (Rogers & Arvedson, 2005). Growth of the face and mouth allow for bulkier foods to be presented by spoon (Stevenson & Allaire, 1991).
Reports of spoon feeding based on gastrointestinal development begin around 5 months CA. Initial stages of spoon feeding involve the child suckling pureed food from a spoon. During early stages of spoon feeding, wide jaw excursions occur as the spoon is brought to the mouth. Wide jaw excursions are early patterns of jaw movement in which downward jaw displacement is exaggerated and poor jaw grading is observed. Jaw excursions indicate low internal jaw stability and support. The phasic bite is also observed during early spoon feeding experiences. The phasic bite is a bite and release pattern that develops around 6 months of age (Rogers & Arvedson, 2005). The phasic bite occurs reflexively and is not a functional bite. Also, the lips remain loose with a reduced seal and the suckle movement pattern will often be observed.

Maturation of the central nervous system and the emergence of volitional control facilitate a more advanced type of spoon-feeding begins after 6 months CA (Bosma, 1986). As volitional control emerges, a mature sucking pattern with up-down movements of the tongue aids in transportation of bulky and mashed foods (Rogers & Arvedson, 2005). Reverting to a suckle response during spoon feeding is common in younger children who are showing more advanced feeding skills that require the tongue, jaw and lips to work independently of one another (Stolovitz & Gisel, 1991). During advanced stages, wide jaw excursions are observed less frequently as the child is better able to grade mandibular movements. In addition, solid lip closure and seal allows for more efficient feeding. Lip closure is essential for removing food from a spoon and creating an anterior seal that prevents food from falling out of the mouth. Disassociation of the lips becomes apparent during mature levels of spoon feeding. However, coordinating lips, tongue and jaw movements remain a challenge (Stolovitz & Gisel, 1991).

As chopped foods and finger foods are introduced, a transition from sucking to a chewing-like pattern occurs. As teeth begin to erupt, initial attempts of chewing are incoordinated and slow (Herring, 1985). Chewing is observed with soft foods and advancing textures. Mastication or chewing is the process of preparing food for swallowing and further digestion (Van der Bilt, Engelen, Pereira & van der Glas, Abbink, 2006). During chewing, food is reduced in size as saliva mixes and moistens the forming bolus. Many factors influence chewing including the presence of teeth, dental occlusion, bite force, saliva production, neuromuscular control and sensory perception during chewing (Van der
Bilt et al., 2006). Munching is an early chewing pattern combined with phasic biting and nonsterotypic vertical movements of the jaw. As teeth erupt, munching stability increases due to increased sensory feedback in the periodontal structures of the teeth and gums (Barlow, 2009). Mastication patterns vary depending on the type of food and sensory feedback. The rhythmic movements of mastication, including basic munching patterns are represented in the cerebral cortex (Barlow, 2009). During chewing, the central nervous system requires information from articulators, particularly the mandible. Information about position, velocity and force applied must be communicated to articulate movement, making sensory feedback critical (Van der Bilt et al.). Neuromuscular control also plays an important role. The muscles of mastication move the mandible and exert graded force in order to cut or grind food. Muscle activity increases if resistance is applied by food (Van der Bilt et al.). Particularly with crunchy foods, the jaw decelerates and accelerates depending on resistance and breakage of food particles. If a disconnect exists between neuromuscular control and sensory feedback, the muscles of mastication may not generate enough force needed to break the food or may generate too great of force and damage teeth (Van der Bilt et al.). As a child transitions from puree to non-puree, neuromuscular control and sensory feedback coordinate allowing chewing skills to advance from an early vertical up-down movements to more advanced rotary chewing patterns. However, jaw and mastication patterns do not develop in a linear fashion, rather different developmental levels of chewing may be dependant on the difficulty of an item presented (i.e. steak versus a soft cookie). A more advance and adult-like rotary chewing pattern emerges around 10-12 months of age (Alexander, 1987).

Biting is another important feeding skill that transfers from reflexive to volitional control. Similar to chewing, biting does not develop in a linear manner. Rather, biting patterns depend on the difficulty of an item presented. The phasic bite reflex diminishes around 9-12 months CA and is replaced by an unsustained bite. An unsustained bite is characterized by an upward movement of the mandible followed by a rapid irregular opening. The unsustained bite develops around 9 months CA and is observed when teeth or gums close on food followed by a new attempt to bite through the food (Rogers & Arvedson, 2005). The unsustained bite is unsteady and the jaw typically grades in an unsteady manner. As greater neuromuscular control and sensory feedback develops, a
graded bite emerges. A graded bite is a controlled upward movement of the mandible that typically emerges around 12 months of age. During a graded bite, the teeth close onto food gradually followed by an easy release for continued munching or chewing.

Advanced lingual movements are also indicative of emerging volitional control. Licking food or liquid off of the lips requires controlled gross and fine motor movement of tongue. Clinically, licking has been reported to emerge around 9 months CA. Anecdotal observations also report tongue lateralization emerges between 6 months up to 15 months CA (Arvedson et al., 2003; Morris, 1985). Tongue lateralization is observed during chewing to transport food from one side of the mouth to the other. Around 10-12 months CA, lateral and diagonal lingual movements allow for food to be brought to the molar surface of teeth (Stevenson and Allaire, 1991). As the skill matures, the tongue acts as a cleaner by clearing the mouth of food particles once advanced textures are consumed (Carruth & Skinner, 2002).

As feeding skills advance, a progression to independent use of utensils and open cups is observed. One important component of self-feeding is reaching, grasping and hand to mouth movements. By 7-9 months CA, most children demonstrate prospective or volitional control of reaching and grasping using visual feedback (Witherington, 2005). A child is able to self-feed by orienting their hand with an object’s position and is able to bring the spoon or cup to the mouth (von Hofsten & Fazel-Zandy, 1984). Prospective control of reaching and grasping improves in accuracy with age. However, a disassociation exists between the two actions, suggesting that reaching or grasping skill may advance more quickly than the other (Gentilucci, Negrotti, & Gangitano, 1997). At 12 months CA, about half of children have been reported to independently self-feed with a spoon (Carruth & Skinner, 2002). By 24 months, about 80% of children have been reported to independently self-feed with a spoon. Often, children will use special baby spoons before they begin transitioning to adult spoons the second year of life (Carruth & Skinner, 2002). Prospective control is also used with open cup drinking, which has been documented to develop between 10 and 24 months CA within clinical settings (Alexander, 1987; Rogers & Arvedson, 2005). During early attempts to drink from an open cup, wide jaw excursions are commonly observed indicating poor internal jaw stability. Anecdotal evidence suggests that as the jaw gains greater stability, wide jaw excursions decrease and the jaw moves
with improved control and ability to grade (Alexander, 1987). Biting or anterior tongue protrusion may occur during open cup drinking as a method to help the child compensate for the lack of jaw stability not observed until roughly 2 years of age (Carruth & Skinner; Stevenson & Allaire, 1991). Flow regulation is also a challenge. As a child transitions from a nipple or spout to an open cup, liquid flow is no longer controlled by the flow rate of the nipple. Rather, flow rate is controlled by the child and the angle at which they tip the cup. Self-regulation and monitoring of liquid flow becomes an added challenge to the already complex suck-swallow-breathe sequence. During initial attempts to drink from an open cup, the suckle pattern is commonly observed (Carruth & Skinner). Lip closure is also a critical component of open cup drinking. The lips must provide enough pressure to form a tight seal around the rim of the cup. Lip pressure develops progressively from 5 months to 3 years of age. Development slows from 3-5 years of age (Chigira, Omoto, Mukai, & Kaneko, 1994). To prevent anterior spilling, lip closure during the swallow is also important. However, lip closure patterns during swallowing are not present until roughly 1 year CA (Stevenson & Allaire, 1991). Open cup drinking frequency has been reported to increases with age, however most mothers do not allow their children to drink independently from an open cup until roughly 24 months CA (Carruth & Skinner). Reluctance may be due to a mother’s concern regarding spills while other mothers may be concerned with increased choking and coughing with independent use of an open cup.

**Purpose of the Study**

Uncertainty exists as to what physiologic event(s) occur that allow a child to successfully drink from an open cup independently. Clinicians have noted through general observation that successful open cup drinking is associated with certain skills including: coordination between the hand and jaw, head and trunk stabilization, controlled grading of the jaw, lip closure and volitional control of the tongue (Rogers & Arvedson, 2005). However, the noted associations are general parameters to help clinicians identify signs of readiness for open cup drinking. No formal research studies have been conducted to systematically analyze open cup drinking development and identify what underlying physiological mechanism(s) allow a child to successfully drink from an open cup. Clinically, open cup drinking has been documented to develop between 10 and 24 months of age
Variability is expected due to individual differences in development and environmental exposure (i.e. practice). Integration of environmental influences and individual differences is a key component in order for a child to eventually drink independently from an open cup. However, to date, neither a detailed analysis of the precise physiologic change(s) which develops nor the optimal environmental conditions has been documented.

**Hypotheses**

1. All children will develop open cup drinking in a similar pattern, but will vary in the amount of time required to learn skills.
2. Children who exhibit less advanced open cup drinking skills will exert more force onto the cup than children who exhibit less advanced open cup drinking skills.
3. Children with earlier/more open cup drinking experience will exhibit more graded mandibular movements than children with less experience/practice with drinking from an open cup.
4. Observable drinking behaviors including wide jaw excursions, tongue protrusion, biting, head dips, and coughing will decrease over time.
5. Children will experience less difficulty coordinating hand to mouth movements as evidence by decreased head dipping, improved cup tilting and improved timing or sequencing of motor movements over time.
6. Design features of cups will influence efficiency of sensorimotor skills including hand to jaw coordination and jaw grading over time.
CHAPTER II

Methods

Subjects

Four subjects from the greater Oxford, Ohio area were included in this pilot study. The subject population included typically developing children who had no significant feeding or birth history. From a feeding perspective, all children in the study showed signs of emerging volitional control of oral musculature and readiness for open cup drinking which can be seen in children ranging from 6-24 months of age (Alexander, 1987). However, age was not the focus of recruitment. Rather children were chosen based on achievement of specific gross and fine motor skills and neurologic development such that the child was ready to transition into the early stage of open cup drinking development (Table 9). None of the subjects could successfully drink from an open cup when recruited for this study, even with caregiver assistance. Subjects were recruited from local daycare centers in Oxford, Ohio and by fliers posted in the Miami University Speech and Hearing Clinic.

Materials

Four different commercially available open cups were used during each trial session, each with a unique combination of design features. One cup served as the “standard” cup in which baseline data was collected. The remaining cups served as three levels of the independent variable. Each level was tested in isolation to avoid variable interference and to measure the effect (if any) of the variable on open cup drinking. Cup 1 was the baseline cup with a small diameter, no rim, and no handles. Levels of the independent variable include:

Cup 2: baseline cup with two handles added
Cup 3: cup with raised rim
Cup 4: cup with larger diameter
Each cup rested in a holder with sensor fixed to the bottom. The sensors collected pressure readings which indicated how much force a child was placing on the open cup while drinking. The cup holders were designed for each cup type and created by Dr. Michael Bailey-Van Kuren, Associate Professor in the Department of Mechanical & Manufacturing Engineering at Miami University. A small hole located towards the bottom of each holder allowed a cord to connect to the pressure sensor. The cord and sensor was enclosed in plastic which minimized any risk of water reaching the electronics. Pressure data was transferred via cord to a Measurement Computing Data Acquisition (DAQ) Board which was directly connected to the laptop computer. The data was captured using TracerDAQ software installed in the laptop. TracerDAQ collected pressure data through channel zero at a sampling rate of 0.10 seconds. After pressure data was collected and saved, used cups were removed from the holder and replaced with a new sterile cup.

A video camera was also used in the study to measure and record movements of the mandible during drinking. Florescent stickers placed on the mandible and cheek in a triangular formation allowed video software to track changes in distances between the stickers. Change in distances translated into movement of the mandible (however this data will not be reported). Video recordings were also used to observe, analyze and code drinking behavior patterns of subjects during trial sessions and in the home environment.
Several checklists and questionnaires were also used in the study. A modified Hawaii Early Learning Program (HELP) checklist was completed by the child’s parent or guardian in order to determine the child’s readiness for open cup drinking. The checklist was modified so that only questions pertaining to gross and fine motor skills related to feeding were asked during every visit. A questionnaire was paired with the checklist to collect information about the child’s current feeding status and related information. The Rossetti Infant-Toddler Language Scale was also used to assess the child’s expressive and receptive language skills. Finally, a home log and video camera were provided for the parent/guardian to track the amount of open cup drinking practice their child received weekly throughout the duration of the study.

**Design and Procedure**

The longitudinal single subject design allowed for systematic observation and documentation of open cup drinking development in four typically developing children. The four participants were seen three times, once every 4-6 weeks. During the initial or baseline visit, informed consent was obtained by the parent or guardian. Clarification was provided for any questions posed. Following consent, a modified HELP checklist was completed by the child’s parent to determine fine and gross motor skills and the child’s readiness for open cup drinking. A parent questionnaire was given with the checklist to collect information about the child’s current feeding status, routines at home, sibling development and dentition. The Rossetti Infant-Toddler Language Scale was also administered which assessed the child’s expressive, receptive language and play skills. The HELP checklist, parent questionnaire and Rossetti Infant-Toddler Language Scale were revisited and updated during each session.

Prior to the open cup drinking test, a standard oral sensorimotor screening was performed to determine emerging oral skills and normal sensory development for each child during the initial visit. A gloved finger was placed in the mouth of the child to assess the strength of the suck and the tolerance for sensory input. Eliciting single step oral commands (i.e. tongue protrusion, lateralization) with auditory and visual cueing was also attempted to assess emerging volitional control. A modified oral sensorimotor screening
was performed during the second and third visits to continue to assess the child's emerging volitional control.

Once the oral sensorimotor screen was completed, the child was brought to a small table and chair set or a highchair. Four open cups will be used during each trial session, each with a unique combination of design features to determine if cup design will facilitate open cup drinking. Each open cup was filled to 80% volume (Table 1) and presented one at a time at random. Prompting to independently drink from the cup was provided as needed. Dependant on the child’s temperament, breaks were also provided between cup presentations. During the three visits, each child was observed and video recorded when drinking or attempting to drink from an open cup. The attempt was deemed successful if the following criterion were observed: the child independently raised the cup to their lips, a tight seal of the lips was formed around rim of the cup, little or no anterior spillage was observed and the lips remained tightly sealed once the liquid bolus is in the mouth. Attempts to drink from an open cup that deviated from this definition were deemed unsuccessful.

Pressure data measuring the force applied to the cup was collected as the subjects drank from the open cups. In addition, videotape was used to measure movements of the mandible during drinking. Three colored stickers were strategically placed on the skin of the cheek and chin area. Distances between the stickers and the reference point were measured. Video software analyzed movement and changes in distance between the stickers, which translated to movement of the mandible (however this data will not be reported). Video recordings were also reviewed for observation, collection of anecdotal evidence and discovering motoric or behavioral patterns among the subjects.

After completion of the open cup test, a simple home log was provided for the parent(s) to track the amount of open cup drinking practice their child was receiving weekly throughout the duration of the study. Parents were instructed to document every time their child practiced, how long their child practiced, and to include any comments they had about their child’s open cup drinking experiences throughout the duration of the study. In addition to the log, parent(s) were provided a small video recording device to capture their child’s open cup drinking practice(s) at home. Parent(s) were instructed to video 1-2 minute samples of their child attempting to drink from an open cup at least 2 times.
between sessions. Training on how to use the video recording device was provided. Parents were instructed to record their child drinking from an open cup in a side or lateral view. The parent(s) were given time to practice using the recording device and adequate opportunity was provided to ask any questions they may have. Contact information was also provided for any troubleshooting, however no problems were encountered throughout the duration of the study. During the second and third visits, the video recorders were charged and a new home log was provided.

Tympanometry was the final step in the research protocol and was completed only on the initial visit. Middle ear compliance was tested to screen for the presence of middle ear infections. When assessing outcomes of the study, the presence of middle ear fluid/infection was important information note, as it may have had impact on data. If middle ear compliance was abnormal, a recommendation would have been made to follow up with a physician. Tympanometry was completed following the open cup drinking test so that if a child became upset by the screen, the cup drinking data was already collected and was unaffected by the child’s reaction to the tympanometry.

Analysis

A quantitative and qualitative analysis will be used to relay the results from this study. Behaviors observed during the cup drinking trials are placed on a timeline that will be examined for patterns of open cup drinking development. Observed behaviors will be coded and compared within and among subjects. In addition, force exerted by the subjects onto the cups while drinking will be compared to the timeline of behaviors to determine if less force is used with advancing cup drinking skills over time. Finally, the amount of change in mandibular movements will also be tracked and labeled to determine if there is a change in mandibular movement patterns over time.
Research Questions:

1. Do all children develop open cup drinking in a similar pattern?
2. Do children who exhibit less advanced open cup drinking skills exert more force onto the cup than children who exhibit more advanced open cup drinking skills?
3. Do children with earlier/more open cup drinking experience exhibit more graded mandibular movements than children with less experience/practice with drinking from an open cup?
4. Will observable drinking behaviors including wide jaw excursions, tongue protrusion, biting, head dips, and coughing decrease over time?
5. Will children experience less difficulty coordinating hand to mouth movements as evidence by decreased head dipping, improved cup tilting and improved timing or sequencing of motor movements over time?
6. Do design features of cups influence efficiency of sensorimotor skills including hand to jaw coordination and jaw grading over time?
CHAPTER III

Results

Descriptive Statistics

Open cup drinking behaviors were examined and compared across subjects, across trials and across cup designs. The number of drinks/drinking attempts for each subject and trial varied. Therefore, percentages were calculated to represent the frequency of the behavior(s). Percentages of drinking behaviors were calculated by dividing the number of times a behavior was exhibited by the total number of drinks/drinking attempts. Percentages were calculated to create consistent and comparable data results.

Subjects

Four subjects, two male and two female were recruited for this pilot study. From a feeding perspective, the subjects showed signs of emerging volitional control of oral musculature and readiness for open cup drinking which can be seen in children ranging from 6-24 months CA (Alexander, 1987). However, this study did not target a specific age range. Instead, this study focused on children who have achieved individual gross and fine motor skills and neurologic development such that the child is ready to drink from an open cup. However, none of the four subjects could successfully drink from an open cup even with caregiver assistance.

Table 2

Gender and age across subjects and trials

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age during visit 1</th>
<th>Age during visit 2</th>
<th>Age during visit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Male</td>
<td>9 months, 25 days</td>
<td>10 months, 23 days</td>
<td>12 months, 4 days</td>
</tr>
<tr>
<td>B</td>
<td>Male</td>
<td>11 months, 23 days</td>
<td>12 months, 17 days</td>
<td>13 months, 18 days</td>
</tr>
<tr>
<td>C</td>
<td>Female</td>
<td>9 months, 27 days</td>
<td>10 months, 25 days</td>
<td>11 months, 22 days</td>
</tr>
<tr>
<td>D</td>
<td>Female</td>
<td>10 months, 22 days</td>
<td>11 months, 24 days</td>
<td>12 months, 22 days</td>
</tr>
</tbody>
</table>
Oral Sensorimotor Examination and Tympanometry

All children appeared within normal limits for sensorimotor development. No gagging or behavior state changes were observed as a result of touch to oral and body regions. Subject C was particularly sensitive to touch in the orofacial region and crying resulted, however increased sensitivity appeared to be due to teething. Excessive drooling was also documented with subject C.

Tympanometry was performed on subjects B and D. Results indicated that no fluid was present in the middle ear space for both subjects. Subject A had pressure equalization (PE) tubes in place due to a past medical history of frequent ear infections, therefore tympanometry was unwarranted. Tympanometry was attempted with subject C, however attempts were unsuccessful due to the child’s temperament and teething sensitivity of the orofacial region. Three months prior, a pediatrician ruled out ear infection for subject C and no signs or symptoms of an ear infection were present throughout the study.

Modified Hawaii Early Learning Profile

The following is a summary of the modified Hawaii Early Learning Profile given to the subjects during each trial of the study. The checklist included 22 gross and fine motor milestones related to feeding skills. Note that the 22 skills were observed with all subjects by the final trial.

Figure 1
Hawaiian Early learning profile results across subjects and trials

<table>
<thead>
<tr>
<th></th>
<th>Subject A</th>
<th>Subject B</th>
<th>Subject C</th>
<th>Subject D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visit 1</td>
<td>14</td>
<td>20</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Visit 2</td>
<td>20</td>
<td>20</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Visit 3</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
</tbody>
</table>
Voluntary Control

Attempts to elicit single step oral commands with auditory and visual cueing were made. The following is a summary of each subject and his or her emerging volitional oral skills or movements made over time. Note that by the final visit, all subjects were able to protrude their tongue on command.

Table 3
Emerging volitional oral skills across subjects and trials

<table>
<thead>
<tr>
<th>Oral Skill</th>
<th>Visit 1</th>
<th>Visit 2</th>
<th>Visit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round lips</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Retract lips</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Protrude tongue</td>
<td>0</td>
<td>1-d delayed response (Subject D)</td>
<td>2- immediate responses (Subjects A/B) 2- delayed responses (Subjects C/D)</td>
</tr>
<tr>
<td>Lateralize tongue - L</td>
<td>0</td>
<td>0</td>
<td>1- delayed response (Subject B)</td>
</tr>
<tr>
<td>Lateralize tongue - R</td>
<td>1- delayed response (Subjects B)</td>
<td>1- delayed response (Subject B)</td>
<td>1- delayed response (Subject B)</td>
</tr>
</tbody>
</table>

Research Questions
1. Do all children develop open cup drinking in a similar pattern?

Consistent behavior patterns existed during the development of open cup drinking in all subjects. Patterns included 1) wide jaw excursions (WJE) characterized by a large downward movement of the mandible, 2) biting characterized by the closing of gums or teeth onto edge or rim of a cup 3) head dips characterized by a forward-downward lunging of the head and trunk, 4) hand to mouth movements characterized by a simultaneous upward and medial movement of arms and hands bringing a cup towards the oral cavity, 5) anterior loss of liquid characterized by water running out of the oral cavity when drinking or swallowing, 6) spilling due to over tilting of a cup while drinking or attempting to drink, and 7) coughing or choking due to suspected penetration or aspiration of liquid. Despite
universal or shared behavior patterns, variances among subjects existed. Distinctive or individualized behavior patterns were observed in three of the four subjects throughout the duration of the study. The following is a descriptive analysis of the individual behavior patterns observed.

**Subject A**

Subject A exhibited a distinctive behavior pattern in 66% of all drinking attempts during the study (Figure 2). The subject appeared to use inhalatory-like movements while tilting the cup to bring liquid inside the oral cavity. Inhalatory-like movements to collect the bolus continued to be observed as the cup was pulled away. The bolus was held in the mouth for the duration of approximately 1 second as the child prepared to coordinate a swallow. Lips were approximated, but full closure did not occur during collection of the bolus or during the swallow. Anterior loss of liquid was common (Figure 3). This pattern was also observed with subjects C (22% of all drinking attempts) and D (13% of all drinking attempts), however the percentage of the behavior was significantly less.

Figure 2

*Subject A percentage of open mouth posture with approximate lip closure*
Subject A percentage of anterior loss from the oral cavity when drinking

![Bar chart showing percentage of anterior loss from the oral cavity for Subject A across three trials: 100%, 55%, and 12%.](image)

Subject B

Wide jaw excursions with tongue protrusion were observed in 100% of subject B’s first open cup drinking trial (Figure 4). This behavior pattern is characterized as a downward movement of the mandible with simultaneous tongue protrusion as the head tilts forward and downward. The frequency of wide jaw excursions with tongue protrusion consistently decreased over the three-month period of the study.

Figure 4

Subject B percentage of wide jaw excursions with tongue protrusion behavior pattern

![Bar chart showing percentage of wide jaw excursions with tongue protrusion for Subject B across three trials: 100%, 25%, and 0%.](image)

Subject C

Full head dips with no use of hands were frequently observed with subject C. The child accounted for 78% of all full head dips observed among participants. The behavior increased in frequency from the first trial to the third trial (Figure 5). Full head dips and
the suckle response were often simultaneous. The suckle, which is characterized by up-down movements of the mandible with tongue protrusion, occurred simultaneously with full head dips 33% of the time. This unique pattern was only observed with subject C and was most prevalent with the baseline and handles cup design (Figure 6).

Figure 5
Subject C percentage of full head dips-no hands behavior pattern

Figure 6
Subject C percentage of full head dips when drinking with correlating cup type

Subject D
No single or individualized behavior pattern noted with subject D, rather a combination of several different universal patterns including full and partial head dips, biting, wide jaw excursions, anterior loss and coughing were exhibited during the study. The suckle response was also exhibited, observed with three of the four subjects (Subject B, C and D).
2. Do children who exhibit less advanced open cup drinking skills exert more force onto the cup than children who exhibit more advanced open cup drinking skills?

Snapshots of graphs from the tracer data acquisition program were used to compare pressure results (force applied) across subjects and trials. Pressure readings during the first trial across subject will not be reported as arrangement and optimal positioning of the sensors was still being explored. In addition, due to being the only cup features that share the same sensor, holder and sensor positioning, the baseline/handles cup is the only cup compared across trials. One exception was made with the rim cup. Force data from the rim cup was used for subject C, trial 3 due to lack of data collected from the baseline/handles cup. Comparison of force collected from the same cup, positioning and sensor ensures accurate and reliable data comparison. Data is displayed via TracerDAQ graphs using identical format and settings which allows applied force readings to be compared visually. In figure 7, visual comparison suggests subject A used greater force when drinking during trial 2 than during trial 3. Subject A also appeared to have greater inconsistency or wavering amounts of force applied over time when drinking during trail 2 as evidence by dramatic increases (spikes) and decreases (dips) in pressure readings. Force applied during trial 3 appeared to be more even with fewer remarkable spikes and dips.

Figure 7
*Subject A: force applied to baseline cup when drinking during trial 2*
Figure 8

Subject A: force applied to baseline cup (top) and handles cup (bottom) when drinking during trial 3
Visual comparison suggests subject B applied a greater amount of force when drinking during trial 2 than during trial 3. However, force applied during trial 3 appeared more inconsistent and wavering as evident by sharp peaks and dips in the recorded pressure amounts.

Figure 9
*Subject B: force applied to baseline cup when drinking during trial 2 (top) and force applied to baseline cup when drinking during trial 3 (bottom)*
Visual comparison suggests subject C applied greater and inconsistent amounts of force when drinking during trial 2 than compared to trial 3.

Figure 10

*Subject C: force applied to handles cup when drinking during trial 2 (top) and force applied to rim cup when drinking during trial 3 (bottom)*
Visual comparison suggests subject D used close to the same amount of force during trials 2 and 3. However force applied became more consistent as evidence of the flattening of the line representation during trial 3 (Figure 11).

Figure 11

Subject D: force applied when drinking from the handles cup during trial 2
Figure 12

**Subject D: Force applied when drinking from the baseline cup during trial 3**

3. Do children with earlier/more open cup drinking experience exhibit more graded mandibular movements than children with less experience/practice with drinking from an open cup?

Previous open cup drinking experiences were uncontrolled for in this study. Per parental report, Subject A was noted to have “many” prior open cup drinking experience. Subjects B and C were reported to have “some” prior open cup drinking experiences and subject D was reported to have “no” prior open cup drinking experience. Throughout the duration of the study, subject A practiced open cup drinking for the greatest amount of time (80 minutes), followed by subject B, C and D with 57, 22 and 22 minutes practiced respectively (Figure 13, 14).
Results are inconsistent. The subject with the most experience (subject A) exhibited the greatest number of graded mandibular movements (Figure 15). However, the subject with the second most experience (subject B) exhibited the least amount of graded mandibular movements. Finally, the subject with no prior open cup drinking experience and the least amount of practice (subject D) exhibited a greater number of graded mandibular movements than subjects B and C by trial 3.
4. Will observable drinking behaviors including wide jaw excursions, wide jaw excursions with tongue protrusion, biting, head dips, and coughing decrease over time?

On average, observable drinking behaviors including wide jaw excursions, wide jaw excursions with tongue protrusion, biting, head dips and coughing decreased over time. Wide jaw excursions were prevalent among all of subjects. The behavior percentage increased from the second to third trial, however the overall percentage of wide jaw excursions decreased from the first to the third trial.
Wide jaw excursions with tongue protrusion also decreased in percentage over time. However, tongue protrusions with wide jaw excursions were only observed with subjects B and C, with a majority of tongue protrusions (87%) observed with subject B.

Biting was another common open cup drinking behavior. Biting behaviors were broken down into three specific behavior patterns. The first is characterized by a head dip with biting, observed with subjects C and D. Biting behavior 1 increased in percentage
from trial 1 to trial 3 (Figure 18). The second biting behavior is similar to the first however the child lifts the cup off the table using their teeth or gums. Biting behavior 2 was observed with subjects A and D when drinking from the cup with the raised rim and decreased over time (Figure 19). The third biting behavior is characterized by biting on the edge of a cup with an erect head and trunk. Biting behavior 3 was observed with subjects A, B and C and decreased over time (Figure 20).

Figure 18

*Percent of biting with head dip for subjects C and D over time*

![Figure 18 Graph]

Figure 19

*Percent of biting with head dips plus lifting cup for subject A and D over time*

![Figure 19 Graph]
Head dips were also commonly exhibited cup drinking behaviors. Full head dips are characterized by a dramatic forward-downward lunging movement of the trunk and head towards a cup with arms and hands along the side of the subject. Full head dips were observed with subjects C and D. While subject D decreased in the number of full head dips by trial 3, subject C began using full head dips in trial 3, never before using them in previous trials. Partial head dips are characterized by a slight forward-downward lunging movement of the trunk and head towards a cup while hands are touching or holding the cup. Partial head dips were observed with all subjects. The percentage of partial head dips increased from the second to third trial, however the overall percentage of partial head dips decreased from the first to the third trial.
Coughing during or immediately following drinking occurred with all subjects throughout the three trials. On average, coughing percentages increased from the first to the second trial and decreased from the second to the third trial.

Figure 23
*Percentage of coughing observed during cup drinking trials*
5. Will children experience less difficulty coordinating hand to mouth movements as evidence by decreased head dipping, improved cup tilting and improved timing or sequencing of motor movements over time?

The percentage of full head dips with no use of hands decreased from the first to third cup drinking trial. The percentage of partial head dips with use of hands consistently decreased across all three trials. Individually, all subjects decreased in both head dipping behaviors excluding subject C who increased in full head dips with no use hands from the second to third trial.

Improved cup tilting and sequencing of motor movements improved over time as evidence by decreased coughing and choking. Regulation of flow from the cup was improved as evidenced by better sequencing of hand to mouth movements, coordinated cup tilting action and timing of the swallow, which resulted in a lower overall percentage of coughing and choking.

6. Will design features of cups influence efficiency of sensorimotor skills including hand to jaw coordination and jaw grading over time?

Design features of the cup appeared to influence sensorimotor skills as evidence by discrepancies of skill acquisition among cup designs. Full and partial head dips with wide jaw excursions should be considered immature cup drinking behaviors. The wide diameter cup feature had the lowest percentage of full head dips with wide jaw excursions (Figure 25). The wide diameter cup also had the lowest percentage of partial head dips with wide jaw excisions (Figure 26). Jaw grading is an advanced sensorimotor skill required for
successful open cup drinking. The overall average shows the baseline cup with no added design feature facilitated the highest percentage of emerging jaw grading, followed by the raised rim feature cup, handles feature cup and the wide diameter feature cup (Figure 27).

Figure 25
*Percentage of full head dips (no hands) with wide jaw excursions by cup design*

![Bar chart showing percentage of full head dips with wide jaw excursions by cup design.](image)

Figure 26
*Percentage of partial head dips with wide jaw excursion by cup design*

![Bar chart showing percentage of partial head dips with wide jaw excursion by cup design.](image)
Figure 27

Percentage of emerging jaw grading in all trials by cup design
RESULTS indicate that a variety of developmental patterns exist as children are learning to drink from an open cup and this variety appears to be within the developmental range of what is considered normal. All subjects exhibited a certain class of behaviors such as wide jaw excursions and biting, however each subject had a unique subset or pattern of individualized behaviors. Interpretations are based on the results of four subjects, therefore conclusions drawn from this study may not apply universally.

Subject A appeared to use inhalatory-like movements in addition to tilting the cup to bring liquid inside the oral cavity. Inhalatory-like movements were also used to form a bolus inside the oral cavity. Lips were approximated, but full closure did not occur during collection of the bolus as well as during the swallow. Anterior loss of liquid was commonly observed with this subject during open cup drinking trials. This behavior pattern has also been observed and documented in utero during bolus collection and ingestion on amniotic fluid. Fetuses approximate their lips once a bolus is collected, however lip closure is not observed (Miller et al., 2003). As Subject A increased coordination of oral structures and the suck-swallow-breathe sequence, inhalatory-like movements and open mouth posture when swallowing decreased. By the end of the study, Subject A was using gravity by tilting the cup to bring liquid into the oral cavity. In addition, lip closure was evident after collection of the bolus and during the swallow. As a result, anterior spillage from the oral cavity decreased. The change in lip closure patterns demonstrated by Subject A is consistent with what is reported in the literature. Specifically that lip closure patterns during swallowing are not present until roughly 1 year CA (Stevenson & Allaire, 1991).

During the last trial, subject A was 12 months and 4 days CA.

Subject B used wide jaw excursions with tongue protrusion frequently when drinking, particularly during trial 1 and 2. Interestingly, subject B also exhibited the greatest amount of emerging volitional tongue control compared to other subjects. Lip licking and tongue lateralization was frequently observed during trial and home sessions as well. Clinically, licking has been reported to emerge around 9 months CA (Arvedson et al.,
1993) and lateralization has been reported to emerge between 6 months up to 15 months CA (Arvedson et al., 1993; Morris, 1985). Considering subject B’s evident lingual control, early tongue protrusions may have been volitionally paired with wide jaw excursions to increase jaw stability during drinking. Anterior tongue protrusion may occur during open cup drinking as a method to help the child compensate for the lack of internal jaw stability which is not observed until roughly 2 years of age (Carruth & Skinner, 2002; Stevenson & Allaire, 1991). Another interesting behavior exhibited by subject B was the unique placement of the foot. Subject B lifted and placed one foot along the edge of the table while drinking. Placing one foot on the table may have provided extra trunk stability and/or may have provided sensory input. This behavior was also observed with subject C.

Subject C exhibited the greatest percentage of full head dips when attempting to drink from an open cup indicating that subject C had the greatest amount of difficulty coordinating hand to mouth movements. With little prior open cup drinking experience, subject C spent several minutes during the beginning of trials 1 and 2 exploring different way to drink from the presented cups. Full head dips were attempted and then used more frequently as a compensation strategy that was often successful, which may explain the percentage increase of full head dips during the third trial. One reason the head dips may have been more successful for subject C is because head dips were paired with the suckle response 33% of the time. During full head dips, the suckle response would be used to extract liquid from the top of the cup. Reverting to an immature suckle response as opposed to the suck is common in younger children who are attempting more advanced feeding skills that require the tongue, jaw and lips to work independently of one another such as cup drinking (Stolovitz & Gisel, 1991). The full head dip with suckle pattern appeared to compensate for a lack of hand to mouth coordination and will most likely continue until the subject can improve the coordination of hand to mouth movements.

Subject D was unique in that a single behavioral pattern was not exhibited. Rather a combination of all behaviors were observed including the suckle response (only observed in subjects C and D), the inhalatory like movements with approximate lip closure (only observed with subjects A and D) and other behavior patterns including biting, head dips and coughing. Perhaps combinations of behavior patterns were observed due to lack of
experience with open cup drinking. Subject D may have used trial and error to determine what behavior facilitated successful open cup drinking.

While all subjects drank from the open cups, different force patterns from the face and mouth was applied to the cup. After analyzing force measurements during drinking, specific trends emerged with advancing cup drinking skills. Subjects exhibited advancing skills including controlled hand to mouth movements and cup tilting as the following pressure patterns were recorded: 1) a reduction in the amount of force applied to the cup when drinking occurred over time; and/or 2) an increase in the consistency or steadiness of the force applied while drinking occurred over time. Subject A and C decreased the amount of force applied and the force became more consistent or steady from the second to third trial. However, the pressure reading for the third trial for subject C was collected from the cup with a rim, which measured force using a different sensor/cup holder than the baseline and handles cup. The two sensors, although identical, may have been positioned in a slightly different manner in the cups causing the sensor to read incoming force differently than the baseline/handles cup. Therefore, it is difficult to differentiate weather the decrease in force was due to study design or the subject’s behavior. Subject B also decreased in force applied from the second to third trial. Subject D used about the same amount of force when comparing graphs visually, but increased consistency or steadiness of force applied. Results for all subjects correlate with improved hand to mouth coordination and cup control. These correlations suggest that force applied decreases and becomes more consistent over time as cup drinking becomes more controlled and movements become more coordinated.

Subjects also exhibited increased coordination of hand to mouth movements and controlled cup tilting as evidence by an overall decrease in the percentage of coughing episodes. Although the percentage of coughing increased from the first to second trial, coughing decreased from the second to the third trial. As subjects developed physically, less anatomical protection may have contributed to increases in coughing or choking episodes from the first to second trial. Perhaps the increase in coughing is an indicator that the subjects were not ready to transition to open cup drinking. However, by the third trial as cup drinking skills improved, subjects were better able to control variables such as
tilting of the cup, flow rate of water from the cup and coordination of breathing and swallowing, making instances of coughing or choking decrease.

Subject A, B and D experienced less difficulty coordinating hand to mouth movements as evidence by decreased head dips over time. Subject C was an outlier, increasing in the amount of head dips exhibited over time as discussed earlier. Head dips were used as a compensation strategy that was often successful for subject C, which may explain the increase. Despite the outlier, all subjects appeared to improve cup tilting and sequencing of motor movements as evidence by decreased coughing and choking episodes over time. Subjects were most the successful coordinating movements with the baseline and rim cups as evident by the least amount of coughing. The handles and wide diameter cups were the most challenging to coordinate as evident by more frequent coughing or choking episodes. Subjects using the handles cup may have been more focused on bringing the cup to the mouth rather than tilting the cup. Coordinating tilting with handles may have been more difficult from a fine motor prospective. Finally, the most coughing and choking episodes were seen with the wide diameter cup. Due to the large opening, greater amounts of liquid can pour out at a faster rate. Subjects may not have been prepared or expecting a faster flow rate and were often overwhelmed with too much water entering the oral cavity at one time. A faster flow rate and overwhelming amounts of water commonly resulted in poor timing or coordination of the swallow.

Emerging jaw grading was also observed in all subjects. Results indicate that emerging jaw grading is the result of individual development and the environment. One factor does not appear to have more influence over another. For example, subject A had the most home practice and prior experience drinking from an open cup and exhibited the most graded mandibular movements among subjects. In addition, parent report indicated that developmentally, subject A was progressing more quickly with motor skills than in other areas. In contrast, subject D had the least amount of practice and no prior experience drinking from an open cup and exhibited the second greatest percentage of graded mandibular movements among subjects. In subject D’s case, development of the child was a large factor in the emergence of early jaw grading as evidenced by no previous open cup drinking practice prior to the study. In any case, environmental factors and development
must be considered. However, one does not appear to carry greater influence than the other.

Throughout the study, observable drinking behaviors decreased in frequency over time including wide jaw excursions, wide jaw excursions with tongue protrusion, biting with the head erect and coughing or choking. The percentage of wide jaw excursions decreased from the first to third trial. The behavior was replaced by emerging graded movements of the mandible. Potential reasons for the decrease in wide jaw excursions include increased stabilization of the jaw, improved control and coordination of hand to jaw movements and improved prospective or visually guided control. The percentage of wide jaw excursions with tongue protrusion observed with subjects B and C also decreased. Possible explanations for the decreased behaviors of wide jaw excursion may include improved jaw stabilization and emerging volitional control of the tongue.

Biting behaviors, such as biting the rim of the cup, varied in frequency and across subjects over time. The percentage of biting with the head erect for subject A, B and C decreased as a likely result of increased jaw stabilization over time. However, the overall percent of biting with head dips for subjects C and D increased over time. The percentage of biting with head dips with lifting of the cup observed in subjects A and D also increased over time. An increase in biting behaviors during head dips may indicate that the jaw is less stable in positions other than when the head is erect. Inconsistent percentages of biting used to stabilize the jaw over time may also suggest that jaw grading does not develop in a linear fashion.

Design features of cups were found to influence efficiency of sensorimotor skills including hand to jaw coordination and jaw grading over time. The efficiency of sensorimotor skills including were judged using two parameters: 1) the percentages of full and partial head dips and 2) the percentage of emerging jaw grading. The highest percentage of head dips (both full and partial) occurred with the baseline and handles cups. The handles feature, which was thought to facilitate hand to mouth coordination, appeared to confuse or inhibit hand to mouth movements for subjects. The wide diameter, which had the least number of full head dips, appeared to be most facilitative of hand to mouth movements. A wider cup diameter may be easier from a gross motor prospective than
compared to a smaller diameter cup. The following is the list of the cup features from most facilitating to least facilitating in regards to hand to mouth coordination.

Table 4

*Cup features facilitating hand to mouth movements: most to least facilitating*

<table>
<thead>
<tr>
<th>Coordination of Hand to Mouth Movements</th>
<th>Most Facilitating</th>
<th>Least Facilitating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wide Diameter</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>Rim</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Handles</td>
<td></td>
</tr>
</tbody>
</table>

The highest percentage of graded mandibular movements occurred with the baseline cup. An average diameter size may have been less challenging to the jaw visually as prospective or visually guided control was developing. The tall height (relative to the other cups) may have made the cup appear closer to the mouth and more accessible to the child as well. The rim cup had the second largest percentage of graded mandibular movements. The rim cup was hypothesized to have the greatest percentage due to the raised rim. Tactile reinforcement along the cup’s edge appeared to guide the jaw and be facilitating to emerging jaw grading skills. The handles cup appeared to draw the child’s focus to hand to mouth movement rather than jaw grading. Finally, the wide diameter was hypothesized and found to be the most challenging and least facilitating for emerging jaw grading. The large diameter (compared to other cups) may have been visually overwhelming causing messages to be sent to the brain associating a wide cup opening with the need to open the mouth wide to receive the cup.
Table 5
Cup features facilitating emerging jaw grading: most to least facilitating

<table>
<thead>
<tr>
<th>Emerging Jaw Grading</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Facilitating</td>
<td>Rim</td>
</tr>
<tr>
<td>Least Facilitating</td>
<td>Handles</td>
</tr>
<tr>
<td>Least Facilitating</td>
<td>Wide Diameter</td>
</tr>
</tbody>
</table>

Environment and home experiences were uncontrolled variables in the study. However, the home log enabled monitoring of important environmental influences of open cup drinking including: 1) dates of when home open cup drinking practice sessions took place 2) the total number of open cup drinking home practice sessions that occurred throughout the duration of the study 3) the total time practiced drinking from an open cup at home throughout the duration of the study 4) a sampling of video recorded home practice sessions. Tracking behaviors and natural open cup practice within the home allows for deeper analysis of how environmental influences may affect development, oral skills and drinking behaviors.

The home log revealed potential patterns of influence among the parents. Participation in the study may have influenced parents to practice open cup drinking more often with their child than if not enrolled in the study. One interesting pattern noted relates to when subjects practiced for the greatest number of sessions. Subjects A, B and C practiced for more sessions on average between the second and third trial than the first and second trial. Reasons for this difference may be that the parent(s) were reminded halfway through the study to record their child if or when the child is drinking from an open cup. An additional reminder following initial instruction to record practice session may have influenced parent(s) to practice and record more sessions during the final portion of the study than with the initial recording. Another reason to explain the significant increase in home practice may be that the subject’s open cup drinking skills were advancing, making
the parent(s) feel more comfortable about practicing with less mess (less spilling) and/or choking as the study progressed.

In addition to examining cup drinking practice and motor development, language development was monitored throughout the study. A pattern was noted among subjects suggesting that motor and language development does not progress equally with one another, rather a stair step progression alternating advancement in motor and language skills occurs. A child may develop more rapidly in one skill area than another at one time. Concentration in the development of one skill area may cause other skill areas to not progress as quickly. For example, subject C demonstrated a large increase in expressive language skills between trial one and trial two (Figure 29). Concentration in language skill development may have correlated with the observed plateau of motor skill development.

During the study, Subject C’s language was rapidly developing, being the only subject to reach more than 10 language milestones outlined in the Rossetti Infant Toddler Language Scale in a four week time period. In terms of motor development, subject C exhibited the least amount of motor skill development, particularly with hand to mouth movements. Subject A’s demonstrated a large increase in language development between trials 2 and 3 (Figure 30). However at the same time, subject A's progression of motor development skills appeared to plateau or possibly regress, particularly with graded jaw movements. Subject A used a greater percentage of graded jaw movements in trial 2 than trial 3. Subjects B and D showed similar stair step patterns of alternating language and motor development, however the pattern was less exaggerated compared to subjects A and C.

Further research is needed using a larger subject population to acquire more information about the development of open cup drinking. Including a greater number of subjects in a future study would allow for 1) a greater understanding of developmental open cup drinking patterns 2) how cup features influence the acquisition of cup drinking skills and 3) the interaction of language development motor development.
Figure 29

Language skills of subject C observed over time

![Subject C graph](image)

Figure 30

Language skills of subject A observed over time

![Subject A graph](image)
Conclusion

Results indicate that a set of consistent behaviors were observed across all subjects as open cup drinking emerged. However, a variety of unique or individualized behavior patterns were also present within the small sample. Some of the observed individualized behavior patterns appeared to be the result of residual developmental patterns that occur in utero and in the early months of life. In addition, results suggest that cup features influence sensory motor skills when drinking. The wide diameter cup appeared to facilitate coordination of hand to mouth movements while the baseline and rim cups appeared to facilitate emerging jaw grading. The rim and baseline cups also appeared to facilitate coordination of cup tilting and the suck-swallow-breathe sequence as evidence by lower percentages of coughing and choking. Finally, pressure results indicated that force applied to the cups when drinking decreased or became more consistent as fine motor skills improved. Further research is necessary to explore these findings in greater depth.
FIGURES

Figure 31

*Cups from left to right: baseline cup, handles cup, rim cup, wide diameter cup*

![Cups from left to right: baseline cup, handles cup, rim cup, wide diameter cup](image)

Figure 35

*Cups outside of holders from left to right: baseline/handles, wide diameter and rim*

![Cups outside of holders from left to right: baseline/handles, wide diameter and rim](image)
## TABLES

### Table 6

*Muscles of the Face and Lips*

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Function</th>
<th>Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbicularis Oris</td>
<td>Pulls lips together in a draw-string like manner to create a labial seal</td>
<td>Lower buccal branches of CN VII</td>
</tr>
<tr>
<td>Risorius</td>
<td>Retracts lips at the corners</td>
<td>Buccal branch of CN VII</td>
</tr>
<tr>
<td>Buccinator</td>
<td>Primarily involved in mastication. Moves food onto surface of the molars. Contraction of muscle constricts oropharynx</td>
<td>Buccal branch of CN VII</td>
</tr>
<tr>
<td>Levator labii superioris, Zygomatic minor, Levatro labii superioris alaeque nasi</td>
<td>Work in conjunction with one another to elevate lip</td>
<td>Buccal branch of CN VII</td>
</tr>
<tr>
<td>Levator Anguli Oris</td>
<td>Draws corners of mouth up and medially</td>
<td>Superior buccal branches of CN VII</td>
</tr>
<tr>
<td>Zygomatic major</td>
<td>Elevates and retracts angle of the mouth (as in smiling)</td>
<td>Buccal branches of CN VII</td>
</tr>
<tr>
<td>Depressor labii inferioris</td>
<td>Pulls lips down and out</td>
<td>Mandibular marginal branches of CN VII</td>
</tr>
<tr>
<td>Depressor Anguli Oris</td>
<td>Depresses corners of the mouth and aid in compression of the upper lip against the lower lip</td>
<td>Mandibular marginal branches of CN VII</td>
</tr>
<tr>
<td>Mentalis</td>
<td>Elevates and wrinkles chin and pulls lower lip outward</td>
<td>Mandibular marginal branches of CN VII</td>
</tr>
<tr>
<td>Platysma</td>
<td>Assists in depression of mandible</td>
<td>Cervical branch of CN VII</td>
</tr>
</tbody>
</table>

(Zemlin, 1998)
### Table 7

**Muscles of the Tongue**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Function</th>
<th>Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior Longitudinal</td>
<td>Intrinsic muscle- elevates tongue tip</td>
<td>CN XII</td>
</tr>
<tr>
<td>Inferior Longitudinal</td>
<td>Intrinsic muscle- turns toward contracted side and downward</td>
<td>CN XII</td>
</tr>
<tr>
<td>Transverse</td>
<td>Intrinsic muscle- pulls edges of tongue toward midline and narrows the tongue</td>
<td>CN XII</td>
</tr>
<tr>
<td>Vertical</td>
<td>Intrinsic muscle- pulls tongue down into floor of mouth</td>
<td>CN XII</td>
</tr>
<tr>
<td>Genioglossus</td>
<td>Extrinsic muscle- prime mover of tongue creating most of the tongue’s bulk. Contraction of anterior fibers causes retraction of tongue. Contraction of posterior fibers draws tongue forward. When both anterior and posterior fibers contract the middle portion of tongue drawn down onto floor of mouth</td>
<td>CN XII</td>
</tr>
<tr>
<td>Hyoglossus</td>
<td>Extrinsic muscle- pulls side of tongue down</td>
<td>CN XII</td>
</tr>
<tr>
<td>Styloglossus</td>
<td>Extrinsic muscle- draws tongue back and up</td>
<td>CN XII</td>
</tr>
<tr>
<td>Palatoglossus</td>
<td>Extrinsic muscle- depresses soft palate and elevates back of tongue</td>
<td>CN XII</td>
</tr>
</tbody>
</table>

(Zemlin, 1998)

### Table 8

**Muscles of Mastication**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Function</th>
<th>Innervation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masseter</td>
<td>Elevate mandible with significant force</td>
<td>Anterior trunch of mandibular nerve arising from CN V</td>
</tr>
<tr>
<td>Temporalis</td>
<td>Elevates mandible and draws it posteriorly if protruded</td>
<td>Temporal branch arising from CN V</td>
</tr>
<tr>
<td>Lateral Pterygoid</td>
<td>Protrudes mandible; works in contrast with the mandibular elevators for</td>
<td>Mandibular branch of CN V</td>
</tr>
<tr>
<td>Muscle</td>
<td>Action Description</td>
<td>Nerve</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>Medial Pterygoid</td>
<td>Elevates the mandible acting in combination with the masseter</td>
<td>Mandibular branch of CN V</td>
</tr>
<tr>
<td>Digastricus Anterior</td>
<td>Depresses mandible when hyoid bone is fixed</td>
<td>Mandibular branch of CN V</td>
</tr>
<tr>
<td>Mylohyoid Muscle</td>
<td>Depresses mandible when hyoid bone is fixed</td>
<td>Mandibular branch of CN V</td>
</tr>
<tr>
<td>Geniohyoid</td>
<td>Depresses mandible when hyoid bone is fixed</td>
<td>CN XII</td>
</tr>
</tbody>
</table>

(Zemlin, 1998)

Table 9

*Open Cup Drinking Timeline*

<table>
<thead>
<tr>
<th>Early Stage: Emerging prerequisite skills</th>
<th>Middle Stage: Inconsistent across environments</th>
<th>Late Stage: Refinement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emerging volitional control</td>
<td>Volitional motor control</td>
<td>Refinement of jaw grading skills and jaw stabilization</td>
</tr>
<tr>
<td>Head, neck and trunk stability</td>
<td>Increased coordination of hand to mouth</td>
<td>Mastery of tongue, lip and hand to mouth control/coordination</td>
</tr>
<tr>
<td>Mature suck</td>
<td>Increased control/coordination of lips and tongue</td>
<td>Able to effectively utilize a variety of cups in different environments without assistance</td>
</tr>
<tr>
<td>Hand to mouth</td>
<td>Improved accuracy of jaw grading</td>
<td></td>
</tr>
<tr>
<td>Lip closure</td>
<td>Inconsistent across environments, cup designs and liquids</td>
<td></td>
</tr>
<tr>
<td>Jaw control/grading</td>
<td>May need adult assistance</td>
<td></td>
</tr>
<tr>
<td>Unable to drink from an open cup, total adult assist</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
REFERENCES


