# University of Alberta

# Breathing Patterns during Face-to-Face Interactions between Children with Autism Spectrum Disorders and their Mothers

by

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# ABSTRACT

Entrainment of breathing patterns during face-to-face interactions is believed to be a critical skill from which conversational timing and turn taking may be derived. Since children with high functioning Autism Spectrum Disorder (ASD) appear to have an absent or altered perception of suprasegmentals and turn-taking, it is reasonable to assume that entrainment may not be observed in this population. A sample of six dyads consisting of a child and his/her mother were recruited for this study: three children were previously diagnosed with ASD and the remaining three were typically developing, matched on chronological age and sex. The results of this exploratory study suggest that entrainment was present in one of the three children with ASD. It is possible that a gradient of entrainment strength, directly correlated with level of functioning or age, exists. The patterns observed mimicked those of the speaker and were not due to increased arousal.

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# INTRODUCTION

## Background

### *Introduction to Autism Spectrum Disorder*

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that typically affects a person's ability to communicate, form relationships with others, and respond appropriately to the environment (Paul, 2001). ASD is a diagnosis that encompasses a heterogeneous group of individuals, including those who do not use oral language and those who do, but in an atypical way, those who have cognitive delays and those who do not. Often, speech and language fail to develop in a typical manner making communication and establishing social relationships extremely difficult. Currently, in Canada, one in 165 children is diagnosed with ASD (Fombonne, personal communication; Centre for Disease Control and Prevention, 2006). It is likely that the majority of these children will require ongoing government-funded support services for education and supervised care.

Reasons for a recently observed increase in incidence of ASD, aside from an increase in public awareness and incentives for services, have been largely debated by researchers. A range of different models attempting to explain ASD are being developed, including candidate gene loci and proposed environmental factors. The existent literature addressing these possible aetiologies is vast, and there is a lack of clear consensus on the specific genes or environmental factors involved. The only agreement in the literature at this point is that ASD appears to be caused by a combination of environmental triggers and genetically mediated vulnerabilities. The following section discusses the anatomical and physiological characteristics of individuals with ASD, as well as aspects of their social-communicative development as they relate to this study.

### *Anatomical and Physiological Characteristics of People with ASD*

There are numerous anatomical and physiological differences between people with ASD and typical children and adults, but it is not clear which of these differences are causes of the disorder and which are the symptoms of the disorder. Moreover, there is no agreement in the literature about which anatomical areas in the brain are specifically responsible for ASD. The primary regions of the brain where structural or functional differences have been found in people with ASD include the medial temporal lobes (usually associated with episodic and declarative memory), cerebellum (integrates sensory perception and motor output) and the frontal lobe (involved in higher order functions such as coordinating, planning and executing behaviour) (Boucher et al., 2005; Filipek, 1999, for reviews). Munson et al. (2006) also found an enlarged right amygdala (regulates emotion and triggers response to danger) in children with ASD.

Another characteristic that has been linked to ASD is a failure or distortion in the development of the mirror neuron system (MNS) (Williams, Whiten, Suddendorf, & Perrett, 2001; Dapretto, Davies, Pfeifer, Scott, Sigman, Bookheimer et al., 2005; Hadjikani, Joseph, Snyder, & Tager-Flusberg, 2005; Fecteau et al., 2006; Oberman & Ramachandran, 2007). A mirror neuron fires not only when an action is performed but also when it is observed. These neurons, first observed in the brains of macaque monkeys (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996), have never been directly observed in humans. However, fMRI, TMS and EEG studies have shown activation of neurons in the inferior frontal cortex and superior parietal lobule in humans both when the subjects performed an action as well as when they saw another individual perform that action (Rizzolatti & Craighero, 2004; Iacoboni, Woods, Brass, Bekkering, Mazziotta & Rizzolatti, 1999). Thus, these brain regions are presumed to house mirror neurons and have been dubbed as the MNS. There is much speculation around the function of mirror neurons; they have been implicated in many fundamental functions including social interaction (Gallese, 1998) and language comprehension (Gallese, 1998; Arbib, 2005). Oberman and Ramachandran (2007) propose that a developmental impairment of functional simulators, especially in the MNS, may be the unifying mechanism that underlies the deficits in recognition, imitation, theory of mind (TOM), empathy, and pragmatic language.

Aside from impairment in the MNS, there are many other theories attempting to make sense of the neuroanatomical and neurophysiological differences observed in the brain of individuals with ASD. The defective mentalising hypothesis (Baron-Cohen, 1995) for example, argues that ASD occurs as a result of the compromising of one's theory-of-mind and, as such, people with ASD cannot mindread, or understand the abstract meanings of communicative gestures essential to a natural way in which the typical person can participate, predict and interpret social behaviour and communication. The executive dysfunction hypothesis (Russell, 1997) arose from the growing body of evidence for executive deficits or deficits in higher order cognitive processing in individuals with ASD. Another predominant theory is the weak central coherence hypothesis (Happe, 1999), which suggests that ASD is due to a bias in the cognitive style of individuals with this disorder. These individuals only have a focus on local information processing instead of a focus that is broad and global in nature. The primary intersubjectivity deficit hypothesis (Hobson, 1993) states that ASD arises from the impairments to neonates' biological mechanisms that underlie socio-affective interactions. Boucher's et al. (2005) research supports this theory in part with neuroanatomical (MRI) and neuropsychological data (neuropsychological tests); they found selective abnormalities of the amygdala and hippocampus in all cases studied and concluded that a disruption between the limbic and prefrontal activity may be central in persons with ASD.

Lastly, another predominant theory that has been cited in recent literature and that was used to explain the findings of this study is the local overconnectivity theory. Courchesne, Redcay, Morgan and Kennedy (2005) suggest that in the ASD population, excessive growth of cerebral circuitry takes place during critical periods of development. This excessive growth then ceases and is followed by reduced pruning. The result is local and short-distance overconnectivity, mainly in the frontal area. This local overconnectivity is accompanied by diminished long-distance connections (e.g., cortical-cortical coupling) which may result in reduced frontal-posterior reciprocal connectivity. Courchesne et al. postulate that the overall implication of this overconnectivity is a 'disconnected' frontal cortex from other cortical and subcortical structures in the brains of people with ASD (2005). The 'disconnected' frontal cortex is consequently not able to integrate information from multiple systems (e.g., emotional, sensory, autonomic, etc.) or provide directive and adaptive feedback (Courchesne et al., 2005).

Beyond structural and functional neuroanatomical investigations, researchers have also looked at other biological subsystems, including the hormone testosterone (Knickmeyer, Baron-Cohen, Raggatt & Taylor, 2005), blood chemistry and altered autoimmune reactivity (Singer, Morris, Williams, Yoon, Hong, & Zimmerman, 2006). A recent study (Yao, Walsh, McGinnis, & Pratico, 2006) found increased in vivo oxidative stress in people with ASD. Oxidative imbalance is a feature of ASD that may cause decreased antioxidant defence and increased free radicals in the body. This imbalance is expected to contribute to the development and clinical manifestations of autism such as abnormal blood flow (Yao et al., 2006). Amaral and Van de Water (as cited in Wallis, 2006, p.34) found aberrant antibodies in the blood of children with a certain type of ASD as well as in their mothers. They hypothesize that these antibodies could alter the development of the brain, leading to autism. Other studies have looked at the neurophysiological-biological aspects of sensory systems because individuals with ASD sometimes exhibit symptoms of hypersensitivity among tactile, oral, visual and auditory modalities (Kern, Miller, Cauller, Kendall, Mehta, & Dodd, 2001; Kern et al., 2006). Individuals with ASD typically display the same type of symptoms as those with sensory integration dysfunction: an inability to cope with normal sensory input. Iarocci and McDonald (2006) reviewed multiple theories for sensory processing deficits, such as an inability to integrate information across contexts, a disruption in attention shifting, or a deficit in an executive function which serves to coordinate different incoming information from various sensory modalities (Iarocci, 2006, for a review). Kern et al. (2006), however, suggested that these sensory abnormalities have the potential for improvement with age.

The aforementioned studies are by no means an exhaustive list of the literature on biological subsystems and ASD and were discussed to familiarize the reader with other existing theories being researched. The literature on the neuroanatomical, physiological and biological differences observed in people with ASD is as vast as the one attempting to identify potential causes for ASD, again with no real consensus on one unifying theory. The most successful theories are the ones that attempt to link the neuroanatomy and functional mechanisms to the behavioural impairment unique to ASD. The theory that implicates a disruption in the MNS and Courchesne's local overconnectivity theory seem to be able to explain many of the anatomical, functional and behavioural observations in this population. However, behavioural findings have not yet been correlated with measures of early brain development (Zwaigenbaum, Bryson, Rogers, Roberts, Brain, & Szatmari, 2005). The next section gives a synopsis of behavioural differences observed in this population that may be a result of the anatomical, physiological and biological differences already discussed.

### *Social-communicative Development in People with ASD*

There have been numerous noted differences between children with ASD and typically developing children in terms of their social-communicative development as well. Infants with ASD prefer objects to faces, do not engage in social interactions as much as typically developing infants and usually avoid eye contact (Paul, 2001). Parents of children with ASD usually report that their infant lacks attachment behaviour. Baron-Cohen, Leslie and Frith (1985) have described individuals with ASD as lacking theory-of-mind, or the ability to place oneself in another person's shoes. According to Zwaigenbaum et al. (2005), infants with ASD exhibit atypicalities in orienting to name, imitation, social smiling, reactivity, social interest and sensory-oriented behaviours. They also show a prolonged latency to disengage visual attention, a tendency to fixate on particular objects in the environment, and decreased expression of positive affect by 12 months of age. In terms of communication, children with ASD make few initiations and are less responsive to efforts to engage their attention. They vocalize less than typical infants and are generally delayed in expressive and receptive speech (Zwaigenbaum et al., 2005).

Individuals with ASD also differ from typically developing people in their perception and production of speech. A study by Kuhl, Coffey-Corina, Padden, and Dawson (2005) revealed significant differences between preschool children with ASD and typically developing children of the same age in both their neural and behavioural responses to speech. Interestingly, the brainwaves of children with ASD who preferred motherese were similar to those of typical children. The brainwaves of these children were also different from those of children with ASD who preferred analog, non-speech signals (Kuhl et al., 2005). In addition, individuals with ASD who use speech do so in an unusual manner, ranging from echolalia and memorized phrases to near normal speech production. However, conversation is difficult to sustain with people who have ASD, because they will often engage in monologues that offer little opportunity for interjection from the listener. The odd nature of their speech and difficulty in social interactions has been, among other things, attributed to difficulties in processing suprasegmentals of speech (i.e., stress, intonation, durational differences, etc.) (Tager-Flusberg, 2001).

Oral communication is the predominant way people exchange information. At a minimum, oral communication involves a speaker, a listener, and a common linguistic code. However, these linguistic codes represent only a portion of communication. Suprasegmental devices including intonation, stress, rate of delivery, and pauses are superimposed on the speech signal and convey information essential to meaning. Pitch, rhythm, and pauses serve to mark syntactic divisions between phrases. Loudness, duration and pitch add additional meaningful information to the linguistic code. Non-linguistic devices such as gestures, body posture, facial expression, eye contact, head and body movement, and physical distance also convey essential information during a communicative event.

Children with ASD have difficulty processing suprasegmentals of speech, which can negatively impact their overall functional communication skills. Paul, Augustyn, Klin, and Volkmar (2005) found an association between suprasegmentals and behavioural ratings of communicative social abilities. Some of the prosodic features of people with ASD include monotonic intonation, aberrant stress patterns, deficits in pitch, intensity (loudness) control, and differences in voice quality (McCann & Peppe, 2003 for a review; Paul et al., 2005; Shriberg, Paul, McSweeny, Klin, Cohen, & Volkmar, 2001).

Evidence from longitudinal and cross-sectional studies indicates that there is a tendency for improper prosodic patterns to persist over time, even when other aspects of language improve (Paul et al., 2005). Whereas there is a dearth of information about therapeutic effects associated with treatment for suprasegmental processing disorders in people with ASD, some interventions have been shown to have an effect even at the molecular level. For example, participants with ASD were intensively trained to recognize differences in affect. Following training, behavioural improvements were reported along higher BOLD fMRI signals in the superior parietal lobule with maintained activation in the right medial occipital gyrus (Bolte, Hubl, Feineis-Matthews, Prvulovic, Dierks, & Poustka, 2006). Although the latter study was limited by a small sample size (N=3), it does suggest that intensive stimulation may be able to change the brain activity in areas of the brain associated with identifying affect.

If suprasegmentals could be targeted in intervention with a similar outcome, then perhaps earlier intervention would allow these children to benefit from social interactions at a younger age. Early and intensive stimulation may be the key to helping affected children develop skills necessary to process the subtle components of pragmatics. An early and reliable protocol for the diagnosis of ASD would be the prerequisite for this early and intensive stimulation in the area of pragmatics.

In addition to an opportunity for early intensive stimulation, an early diagnosis has other benefits. For example, Howlin and Moore (1997) found that parents were more satisfied with the diagnostic process if it occurred in the preschool years. At the same time, because eligibility for participation in intensive intervention programs is often limited to children who have a formal diagnosis of ASD, early identification and accurate assessment are crucially important (Moore & Goodson, 2003). Despite all the benefits of increased opportunity for social interaction and parental satisfaction, a formal diagnosis of ASD is rarely given prior to the age of three years. Moreover, therapies that address vocalization and speech are not usually provided until these children enter preschool or elementary school. A need for a reliable protocol that allows for an early diagnosis of ASD is obvious, but there are numerous difficulties surrounding this issue, some of which are discussed in the following section.

### *Early Diagnosis*

According to the Diagnostic and Statistical Manual of Mental Disorders, ASD has an onset prior to the age of three years and is characterized by delays in social interaction, language as used in social communication, or symbolic or imaginative play (Diagnostic and Statistical Manual of Mental Disorders IV, B, 2003). It is very difficult, however, to make an early diagnosis because these aspects of behaviour are not evident until later years. Until recently, diagnosis of ASD was not made until 5.5 years of age and of Asperger Syndrome until 11 years of age (Howlin & Asgharian, 1999). However, children now are being identified and diagnosed as early as 18 months (Zwaigenbaum et al., 2005).

The difficulty in accurately diagnosing ASD lies in trying to differentiate it from other, more common problems of speech and language delay and general developmental delay (Charman & Baird, 2002). A current challenge in diagnosis is the fuzzy boundary between ASD and other disorders having overlapping symptoms such as Attention Deficit-Hyperactivity Disorder, nonverbal learning disorder, and other speech and language problems. It is also difficult to sort out what could be seen as eccentricity versus what could be a real social deficit (Lord, 2005, personal communication). For these reasons, a multidisciplinary approach is required (McConachie, Salt, Chadury, McLachlan, & Logan, 1999), which adds to the complexity of the diagnostic process. An extensive amount of information is also necessary for an accurate diagnosis, including a detailed developmental history, descriptions from parents of the child's everyday behaviour, and direct assessment of the child's social interaction style, communicative behaviour and intellectual functioning. Clinicians will want to observe and assess the child in multiple contexts and with same-age peers as well (Charman et al., 2002). Currently, there are numerous screening tests available such as the Checklist for Autism in Toddlers and the Early Screening for Autistic Traits. However, according to Lord (2005, personal communication), these tests miss almost 50% of the children that should be diagnosed. To increase the number of early diagnoses, people who come in contact early on with the child, such as physicians, need to be armed with current knowledge and an observant eye during regular health maintenance visits. An added complication is the fact that even typically developing children may not wish to interact or play with a stranger in a doctor's office (Lord, 2005, personal communication). Despite this, there is compelling evidence, as suggested by Zwaigenbaum (2001) that identification can be carried out by physicians on children who are 18 months to 2 years of age.

Recent work by Zwaigenbaum et al. (2005) investigated possible early abnormalities in attention, behaviour reactivity, emotion regulation and activity level. They found several specific behavioural markers that can be observed as early as 6 months. Zwaigenbaum et al. (2005) reflect that previous studies had little focus on the developmental sequence of the behavioural markers or their relation to underlying neurodevelopmental mechanisms. The initial findings from his longitudinal study of infants at high risk for autism (siblings of children with autism) indicated that atypical neurodevelopment characteristics of ASD are manifested in behaviours observed in the first year of life. These behaviours include atypicalities in eye contact, visual tracking, disengagement of visual attention, marked passivity and decreased active level at 6 months followed by extreme distress reactions (Zwaigenbaum et al., 2005). One of the limitations of using just behavioural observations, as pointed out by Zwaigenbaum, is the question of how long does one wait to ensure that these behaviours are indeed reflective of ASD (Zwaigenbaum presentation, Autism Rounds at Glenrose Rehabiliation Hospital, Edmonton 2007). An objective and reliable marker that could be administered to children at risk of having ASD and that could be used early on in life is thus necessary. This study will investigate a possible physiological marker of ASD that could be used in concert with behavioural markers for early detection and diagnosis of this population from Zwaigenbaum et al. (2005). The hypothesis of this study is that this physiological marker exists at the level of conversational synchrony.

### *The Importance of Conversational Synchrony*

Synchrony or behavioural entrainment has been defined as the modification of one's behaviour to coordinate with another (Bernieri, Reznick, & Rosenthal, 1988; Condon & Ogston, 1966). Conversational synchrony is a fundamental suprasegmental aspect of human social interaction and is thought to be an absolutely essential element of speech (Wylie, 1985). Conversational synchrony is central in maintaining a comfortable or perceived pleasant conversation where partners take turns naturally and without conscious thought. Since the two communication partners are not linked by a shared neural system, it is hypothesized that they must rely on cognitive-linguistic factors and visual/auditory feedback to regulate their conversational dynamic (Schmidt, Carello, & Turvey, 1990; Schmidt & O'Brien, 1997). In other words, speech production processes must be closely linked at turn-taking moments to facilitate the dynamic interchanges between listeners and speakers (McFarland, 2001). According to Warner, Waggener, and Kronauer (1983), coupling between the vocal activity pattern of a speaker and that of his partner is stronger than the coupling between the vocal activity pattern and respiratory cycles of the speaker himself. Social constraints, therefore, have more influence on vocal activity level than physiological factors, to a certain degree. Wilson and Wilson (2005) propose an oscillator model of the timing of turn-taking where endogenous oscillators in the brain of the speaker and listener become mutually entrained on the basis of the speaker's rate of syllable production.

Communication synchrony is believed to be a developmental phenomenon, driven by innate behavioural and physiological rhythm generation. Preliminary studies have shown that communicative rhythmicity may be related to infant health, maturity, and language-learning deficits (Condon, 1982; Lester, Hoffman, & Brazelton, 1985). This rhythm generation may be under automatic neurological control such as the medullary centre or other central pattern generators. However, the general cognitive process involved in face-to-face conversation (McFarland, 2001) and abstract processing of suprasegmentals, most importantly timing, appear to also be essential. The atypical neurodevelopment characteristics of ASD observed by Courchesne, Carper and Akschoomoff (2003) and their manifestation in the behavioural markers identified by Zwaigenbaum et al. (2005) suggest that conversational synchrony may not be observed in the ASD population at the behavioural level (e.g., a lack of a comfortable conversation) or at the physiological level. In other words, if children with ASD are not picking up on the conversational rhythmicity and other suprasegmental aspects of speech, then they will not entrain to the speaker and process cues for turn taking or reciprocal vocal interaction.

To better understand how conversational synchrony can be measured using respiratory movements, a brief background on the respiratory system and entrainment behaviour observed in lower animal species follows.

### *The Respiratory System*

Breathing patterns are controlled by the respiratory centre in the brain stem. The basic rhythm of respiration is determined by nerve impulses generated in the inspiratory area, located in the medulla oblongata. However, the breathing rhythm can also be modified in response to inputs from other brain regions and receptors in the peripheral nervous system. Nerve impulses from the hypothalamus and limbic system for example, can stimulate the respiratory centre, allowing states and emotional stimuli to alter our breathing patterns (Tortora & Grabowski, 2000).

Neuronal growth of the respiratory centres occurs prenatally with a burst of neuronal growth just prior to birth. Synaptic connections then decrease gradually and differentially near the brain stem region just after birth, allowing respiratory regulation. Studies by Sammon and Darnhall (1994) and Ingersoll and Thoman (1994) have shown that typically developing human neonates are capable of accomplishing these temporal relationships via respiratory entrainment to external regular oscillators (e.g., movement or sound). Sammon et al. (1994) recorded the respiratory-abdominal movements of neonates (N=18) while they were being rocked at different rates. When a coherence analysis was done between the respiratory movements of the infants and the rocking cycle the researchers found strong entrainment to the swinging frequency (Sammon &

Darnhall, 1994). Similarly, Ingersoll et al. (1994) found that when irregularly breathing neonates were provided with a regularly 'breathing' teddy bear in their cribs, their breathing entrained to the optimal rhythm provided by the bear. The premature infants in the experimental group (N=19) showed significantly more quiet sleep, less active sleep, and increased respiratory regularity than their control counterparts (N=17) after 12 weeks. The authors suggested that entrainment of the breathing patterns to that of the bear facilitated neurobehavioural development of the infant's own biological rhythm (Ingersoll & Thoman, 1994).

### *The Importance of Entrainment*

Warner (1996) suggested that biological rhythmicity is important in the coordination between organisms, between organisms and their environment, and between physiological systems within a given organism. Communication synchrony is exhibited across animal species and serves many vital functions such as mating, locating others and general survival. For example, having an effect on a communication partner's biological rhythms without any physical contact is also exhibited in lower animal species as seen in fireflies and *Gymnotiform* electric fish. In fireflies, alternating series of excitatory and inhibitory periods initiated by the incoming male flash combined with a short-term memory of previous flashes and background noise to determine the probability of a particular female response. Rival males can synchronize their flash signals (Copeland & Moiseff, 2004) and if two synchronizing *Pt. malaccae* males find each other at close distances, they repel each other aggressively (Buck and Buck, 1968; 1978). *Gymnotiform* electric fish also communicate with action potentials, a signal created by discharge from the electric organ, and they can modulate the rate of firing in relation to their partner during courtship. The male and the female maintain constant rate differences while they vary rates of firing. Since entrainment patterns in communicative behaviour are observed even in primitive nervous systems, it is reasonable to assume that this phenomenon is controlled at a subcortical level and therefore may be a salient component of typical development in functional communicative ability.

### *Respiratory Movements as a Measure of Synchrony*

Based on the previous discussion it was reasoned that a physiological behaviour such as breathing would serve as a marker of conversational synchrony. Previous work by Hoit & Hixon (1986) and Boliek et al., (1996; 1997) have shown that breathing used for speech is different than breathing used for ventilation. Since speech and breathing are closely coupled, it is reasonable to assume that the breathing patterns of individuals and the way in which they entrain to their conversational partners play a role in the underlying aspects of phrase perception and phrase production. There are several additional advantages for using respiratory movements as a measure of synchrony: the respiratory system may provide essential markers that differentiate physiological processes associated with basic biological function (e.g., ventilation) from the ones essential to the production and perception of speech (e.g., respiratory control for speech). McFarland (2001) also reasoned that the respiratory system is a sensitive measure of synchrony because it can be used in the absence of vocal activity (i.e., when the communication partners are listening) and it also provides a continuous measure during the interactions as the subjects change between the roles of speaker and listener.

The following section summarizes the literature on conversational synchrony as measured by respiratory movements.

### *Previous Studies on Conversational Entrainment*

McFarland (2001) found that, in face-to-face spontaneous conversations between adults, the breathing pattern of the listener entrained to that of the speaker: shorter inspiratory durations followed by longer expiratory durations were observed. Previous studies have shown that when conversational partners are placed in separate rooms and provided only with the audio and video signal of their partner, turn-taking between them became synchronized (O'Conaill, Whittaker, & Wilbur, 1993; Sellen, 1995). Therefore, a more natural turn-taking process takes place within face-to-face interactions (McFarland, 2001). He also argued that the observed respiratory patterns are unlikely to be due to increased arousal or cognitive activity, because if they were, we would have seen both the inspiratory and expiratory durations decrease and respiratory rate increase (McFarland, 2001). This latter pattern was previously seen during performance of mental arithmetic, audiovisual stimulation and passive listening to speech (Boiten, 1993; Mador & Tobin, 1991; Rigg, Inman, Saunders, Leeder, & Jones, 1977; Shea, Walter, Pelley, Murphy, & Guz, 1987). Furthermore, entrainment does not seem to be affected by attitude similarity or attraction between the two members of a dyad (McGarva & Warner, 2003).

Figure 1 shows how speech breathing patterns differ from those of rest breathing. During face-to-face conversation, the listener's breathing patterns begin to resemble those of the speaker, that is, the listener's breathing patterns entrain to those of the speaker.

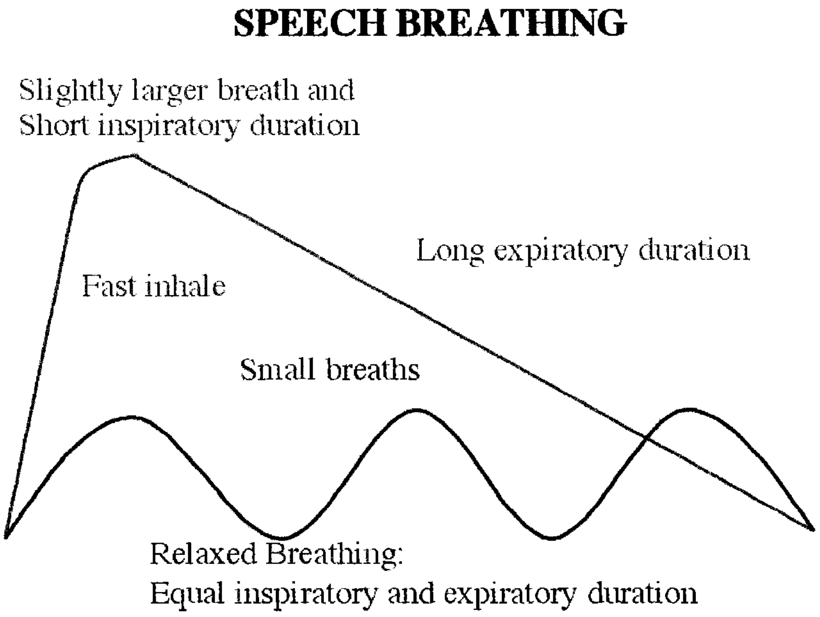
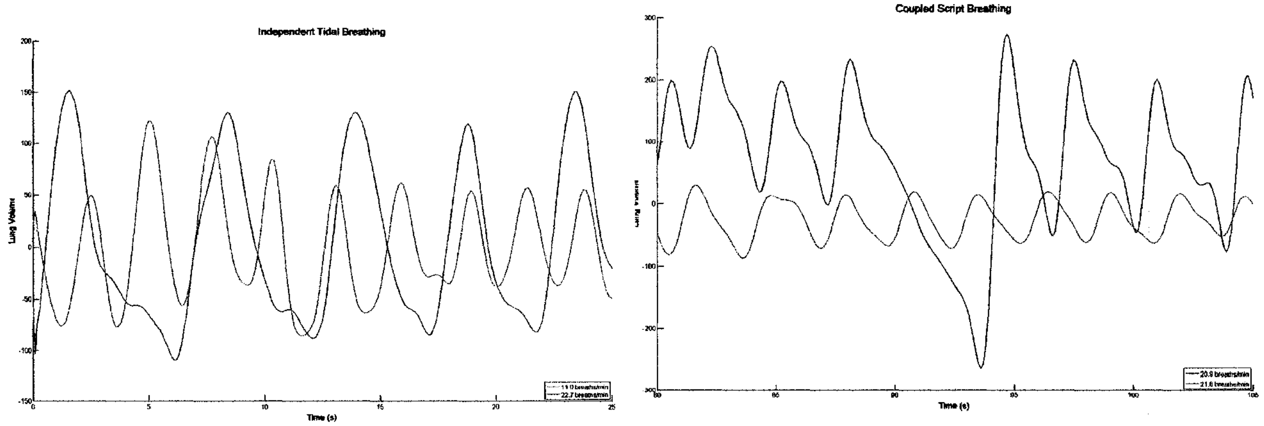


Figure 1. Speech breathing patterns (red) compared to tidal breathing patterns (blue).

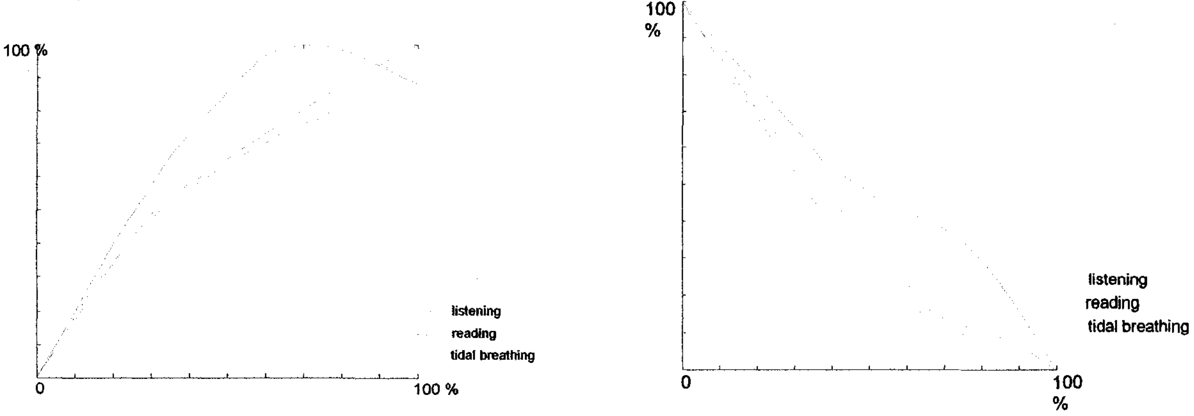
Recently, Boliek has replicated McFarland's (2001) finding in adult conversational partners (Boliek, Welsh, Homaeian, Jones, & Sherkat, 2006b). The figures below show the breathing oscillations (inspiration followed by expiration) in two adults during tidal breathing (Fig. 2a) and during face-to-face conversation (Fig. 2b).



2a. 2b.

Figure 2a. Independent tidal breathing in two adults: person A (red) is breathing at a faster rate than person B (blue). b. Persons A and B are alternating turns in speaking and listening to each other: their respiration rates and patterns are now closer to one another. Boliek et al., 2006b (with permission).

The following figures show average waveforms for inspiration (Fig. 3a) and expiration (Fig. 3b) of all the participants in the study, under different conditions (Boliek, et al., 2006b). The waveforms during the listening task are qualitatively different than the waveforms for the reading tasks and for rest breathing (obtained when participants were alone).



3a. 3b.

Figure 3a. Mean inspiration waveforms: during the listening task (red), the inspiration waveform looks qualitatively different than it does during the reading task (green) and the tidal breathing task (purple). b. Mean expiration waveforms: during the listening task (red), the expiration waveform looks qualitatively different than it does during the reading task (green) and the tidal breathing task (purple). Boliek, et al., 2006b (with permission).

Researchers have then wondered whether or not breathing entrainment can be observed in infancy and the implications for social-communicative development. As stated previously, preliminary studies have shown that communicative rhythmicity may be related to infant health, maturity and language learning (Condon, 1982; Lester et al., 1985). In addition, moderately coordinated infant-caregiver interaction has been found to be predictive of best developmental outcomes (Jaffe, 2001). Boliek and Martinez (2002) observed respiratory and heart-rate synchrony in infants as young as 7 weeks old. Figures 4 and 5 show breathing entrainment patterns during face-to-face interactions between a mother and her 7 weeks old infant (Martinez, 2002, p.37, 40).

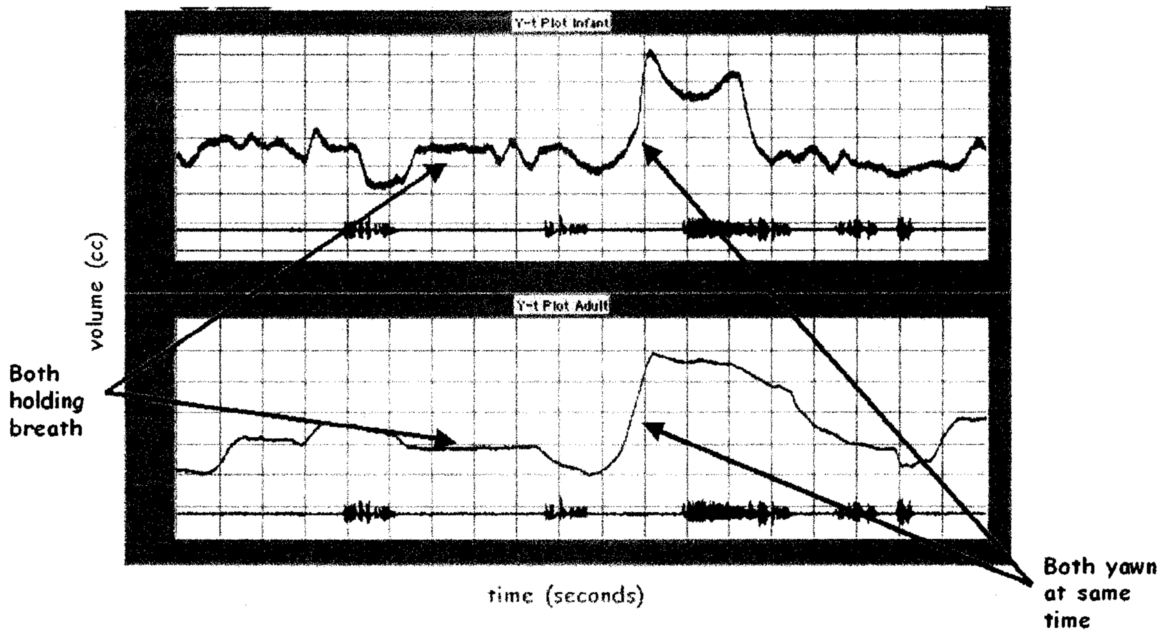


Figure 4. Exemplar of synchronous respiratory behaviour between infant and mother. Both infant and mother hold their breath and yawn at nearly the same time. Martinez, 2002, p.37, 40 (with permission).

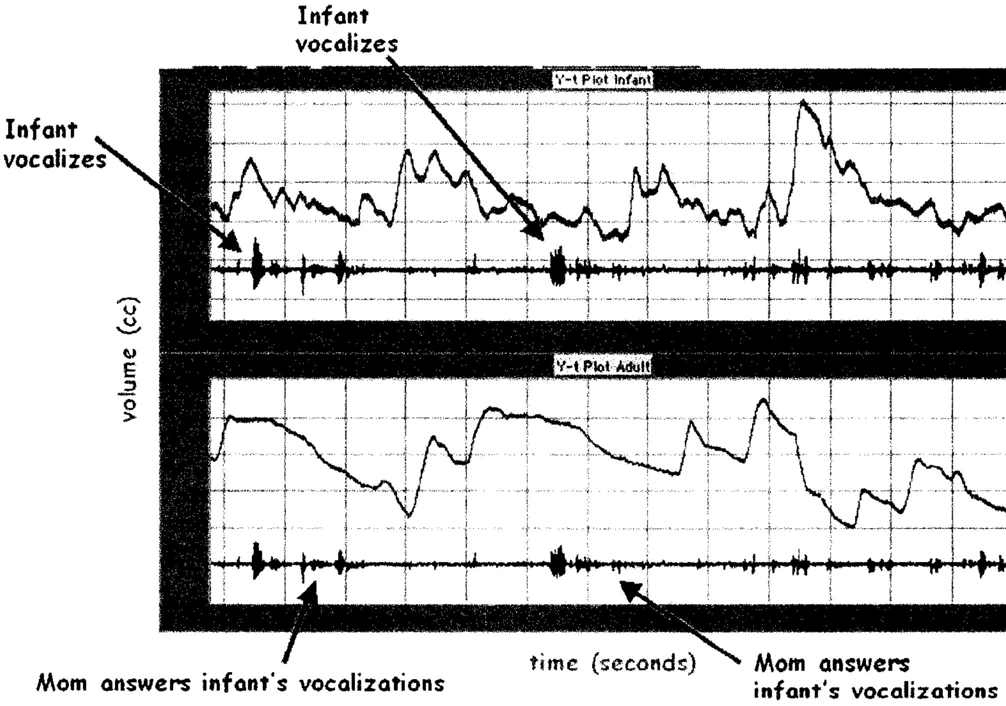


Figure 5. Exemplar of the most complex respiratory entrainment observed in the study that occurs during a vocal exchange between mother and infant. The figure demonstrates infant entrainment to the slow or *carrier* frequency exhibited by the mother while maintaining a much faster breathing frequency commensurate with a respiration rate needed for ventilation. Martinez, 2002, p.37, 40 (with permission).

Boliek and colleagues have analyzed 9 other infant-mother dyads for the presence of breathing entrainment during face-to-face interactions (Boliek, Jones, Homaeian, Roseborough, Constantinescu, Donescu, 2006a). If synchrony is apparent in typically developing infants as a marker of general physical health, maturity and developmental outcomes (Condon, 1982; Lester et al., 1985; Jaffe, 2001), then perhaps it is a critical element from which conversational rhythmicity is derived. Since children with high functioning ASD appear to lack or have an altered perception of suprasegmentals and turn-taking during a conversation, it is reasonable to assume that entrainment in breathing patterns may not be observed in this population. This lack of entrainment may be an early physiological marker of this syndrome and not an artefact of the environment of individuals with ASD.

### *Potential Significance for this Study*

The data from this study will serve as a foundation for a larger study designed to assess infants who may be at risk for ASD. As mentioned earlier, at present, a definite diagnosis of ASD is rarely given prior to three years of age. If we can reliably detect an altered or missing physiological marker in very young children with a diagnosis of ASD, then we may be able to ultimately employ it as a means for early identification (i.e., as early as 7 weeks of age). This physiological marker refers to the absence of entrainment of breathing patterns during face-to-face interactions, an indication that children with ASD are not picking up on conversational synchrony and perhaps other suprasegmentals of speech.

## Purpose

The purpose of this research was to enhance our understanding of emergent physiological characteristics of communicative entrainment during early face-to-face interactions with young children diagnosed with ASD and a matched group of young, typically developing children. Entrainment in breathing patterns, for the purposes of this study, was looked at in terms of a significant perturbation in the breathing waveforms from baseline, or tidal breathing waveforms, to waveforms produced during conversation. The reason for this decision was that phase analysis, another method of determining the presence of breathing entrainment, is not yet fully understood even in the adult population. Moreover, it requires lengthy samples of interaction, something that was foreseen as implausible with an ASD population. It was hypothesized that this perturbation is characterized by shorter and faster inspirations and longer and slower expirations (similar to speech breathing). Physiological markers of entrainment were identified through a series of analyses of mean inspiratory and expiratory waveform shapes as well as mean inspiratory and expiratory durations from signals generated by each dyad member. These differences in shapes and time durations of expiration and inspiration waveforms can be interpreted as markers of systematic perturbation in the breathing patterns presumably associated with conversation.

The general prediction for this study was that young children who have a diagnosis of ASD would not produce respiratory patterns that are indicative of communicative entrainment during face-to-face interactions with their mothers. My hypothesis was two-fold: (1) in typically developing children, inspiration and expiration patterns would differ depending on whether they are at rest or listening to their mother; and (2) in children who have a diagnosis of ASD, the inspiration and expiration patterns would be the same regardless of whether they are at rest or listening to their mother. Support for my hypothesis will be interpreted as initial evidence for a physiological response difference between young children with ASD and typically developing children during face-to-face interactions. If this physiological marker exists in typically developing infants and young children, but not those with ASD, then the absence of this physiological response may serve as a preliminary marker for early identification of ASD.

# METHODS

## Participants

### *Sample Size*

A sample of six dyads consisting of a child and his/her mother was recruited for this study. Three of the six children were previously diagnosed with having ASD. These children and their mothers formed the experimental group dyads. The remaining three children were typically developing, who, together with their mothers, formed the control dyads.

Table 1. Control and Experimental Dyads.

| **Dyad** | **Group** | **Child Participant** |
|---|---|---|
| 1, 3, 5 | Control | Typically developing |
| 2, 4, 6 | Experimental | Diagnosed with having ASD |

For each individual in a given dyad, under each condition (to be described in *Procedure*), numerous samples of breathing patterns were taken. Each sample, in turn, yielded multiple inspiration and expiration waveforms. As a result, the number of waveforms of breathing patterns per subject was relatively high. Previous studies have shown a significant difference with a small sample size: a study done by Boliek, et al. (2006b) and another by McFarland (2001) on breathing entrainment patterns in adults and using similar methods of analysis revealed significant results with a sample size of 10 dyads.

### *Selection and Matching Criteria*

For the experimental dyads, children with ASD were selected based on age (2 years 6 months and 5 years 0 months old) and on level of functioning (high- to moderate- functioning). These children were recruited through Family Linkages Foundation of Alberta (FLFA), a non-profit organization based in Edmonton. FLFA offers behavioural consultation and specialized services (Occupational Therapy, Speech Language Pathology, Physical Therapy, Psychology) to preschool and grade-school aged children with autism and their families. For the control dyads, typically developing children were selected to match the chronological age (+/- 6 months) and gender of the children in the experimental group. This age range was chosen because most children are not diagnosed with having ASD prior to this age (Howlin, & Moore, 1997). It is possible that children who are older and were previously diagnosed of having high to moderate functioning ASD may exhibit entrainment of breathing patterns as a result of increased experience in social interactions and intervention. Thus, determining the presence or absence of breathing entrainment patterns during face-to-face interactions in older children (much older than 5 years and 0 months) would result in inconclusive data. Similarly, a population much younger than the one chosen (below the age of 2 years and 6 months) would not have undergone the critical period with respect to accelerated growth and premature connectivity in brain development (Courchesne et al., 2005). A younger population would be better suited for a longitudinal study, to establish which of the children are later diagnosed with ASD.

### *Exclusion Criteria*

The exclusion criteria for these participants were chosen to eliminate as many confounding variables as possible, such as respiratory abnormalities/ difficulties, other developmental disorders and health problems. They were also set in place to ensure the safety and well being of the participants.

Children selected to participate in this study met the following criteria:

- be from healthy, full-term pregnancies;
- have a negative history of respiratory difficulties, cardiac disease, prenatal drug or alcohol addiction, physical or metabolic abnormality;
- be from a non-smoking household;
- be without a family history of speech, language, or learning difficulties;
- caregiver had no concerns regarding child's hearing.

Mothers involved in this study met the following criteria:

- have a negative history of respiratory difficulties, cardiac or respiratory disease, and physical abnormality affecting chest wall movement;
- be non-smokers;
- have a negative history of speech, language or learning difficulties.

## Equipment

A variable inductance plethysmograph—Respitrace (Ambulatory Monitoring, Inc., Ardslet, NY, U.S.A) was used to measure chest wall kinematics. This system was found by Boliek, et al. (1996) to be more reliable and less problematic than a magnetometer device because there are no coils to be dislodged by the child. It also allowed for a natural, unencumbered measurement of chest wall movements. Figure 6 is a schematic diagram of the equipment.

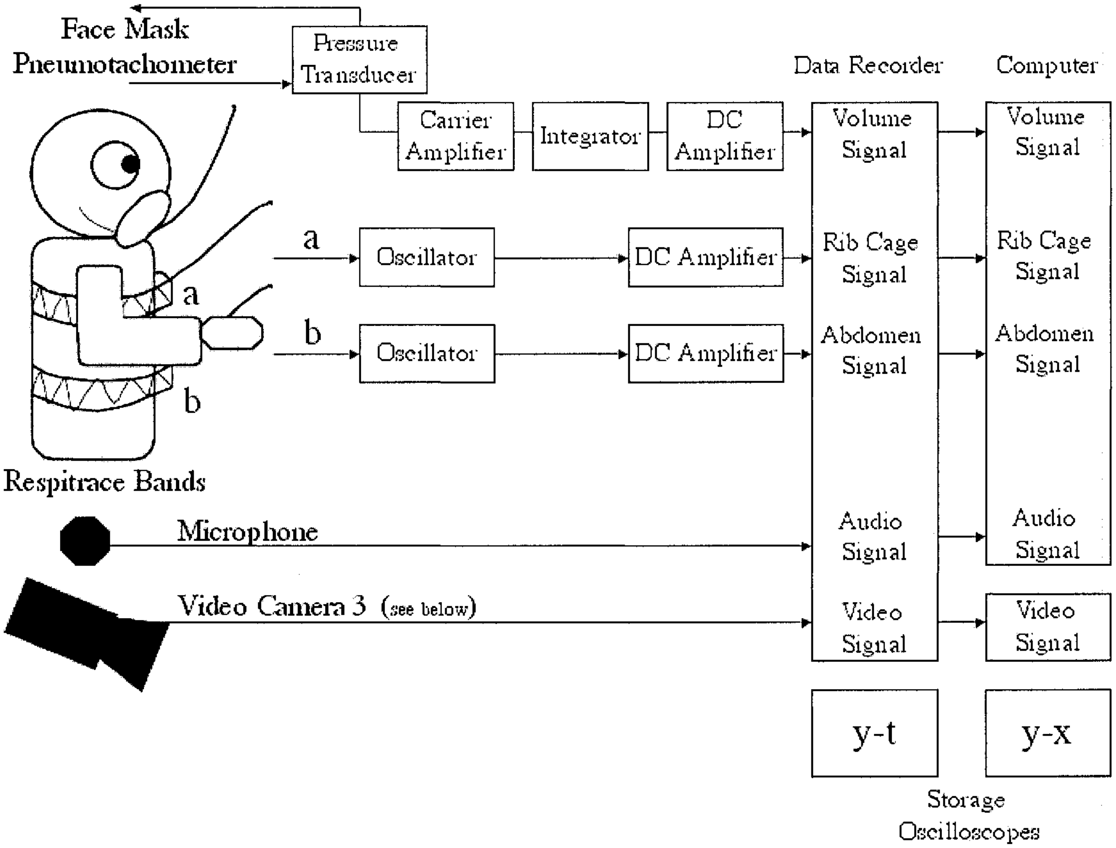


Figure 6. Schematic Diagram of the equipment used.

Transduction bands from the Respitrace were placed on the ribcage and abdomen of each subject. The band for the ribcage was positioned with its upper edge slightly below the axillae and its lower edge slightly below the nipples. The band for the abdomen was positioned with its upper edge slightly below the costal margin and its lower edge slightly above the iliac crests (Stradling, Chadwick, Quirk, & Phillips, 1985).

Each band encircled its respective chest wall part and sensed changes in size. As the wires in the bands were expanded, inductance/ impedance changed in reference to oscillating frequency. Size was expressed as the average of an infinite number of cross-sections through the height of a band. In this manner, the ribcage and abdomen were each represented by an output that was related to change within an ideal cylinder described by its average cross-sectional area. Subsequent to calibration, outputs were used as estimates of the volume displacements of the ribcage and the abdomen. These two parts contribute independently to the lung volume changes. Therefore, the sum of the ribcage and abdomen outputs was used as an estimate of the volume displacement of the lung (Watson, 1979). Outputs for the ribcage ("a", in Fig. 6) and the abdomen ("b," in Fig. 6) respectively, were displayed in a y = x mode on a storage oscilloscope and recorded separately on a data recorder.

Flow was captured by a face-mask, channelled through a pneumotachometer, sensed by a pressure transducer and amplified. The resulting signal was integrated to obtain a volume output that was displayed in a signal-over-time mode on a second storage oscilloscope and recorded on the data recorder. The face-mask was only worn during a calibration protocol. Otherwise both mother and child were unencumbered.

Video recordings were obtained with the use of three video cameras mounted on tripods: one faced the mother (camera 2, Fig. 7), one faced the child (camera 1, Fig. 7) and one in the middle captured both the mother and the child (camera 3, Fig. 7). The video signals captured from camera 1 and 2 were used to analyze eye gaze and signals from camera 3 were used to analyze the interaction between mother and child. The output from camera 3 was also displayed on a video monitor and recorded on the data recorder.

Audio recordings were obtained with the use of a small condenser microphone placed on a table between the mother and the child. The signal from the microphone was amplified and recorded on the data recorder.

A custom built Vetter data recorder was used to collect simultaneous kinematic signals from the child and mother time-locked to video and audio signals. All signals were digitized (National Instruments A/D boards and video processor) and stored and analyzed using customized data acquisition and analysis software (InfantWithVoice/runtime, in LabView 7.0). Waveforms were then transferred to MATLAB (The MathWorks, Inc.) software for further analyses as explained in the *Analysis*. The laboratory of Dr. Boliek has an established and reliable protocol that allowed us to examine a constellation of variables thought to drive conversational rhythmicity in young children and their mothers.

## Design

The independent variable in this study was the type of dyad: children previously diagnosed as having ASD and their mothers formed the experimental group; typically developing children and their mothers formed the control group. The dependent variable was the presence or absence of breathing entrainment patterns. The four conditions in this experiment for which breathing patterns were acquired were:

1. Tidal Breathing: Subjects were at rest, with no eye contact between dyad

members. This condition was used to obtain baseline measures of the breathing patterns.

2. Independent activity: Subjects were engaged with an inanimate object (i.e., the child played with a toy or looked at pictures in a book/television, while the mother looked at pictures in a magazine). There was no eye contact between dyad members and there were preferably no vocalizations. This condition was included to help tease out confounding variables such as levels of excitement and attention during the interaction.

3. Face-to-face, no speech: Dyad members remained face-to-face with one another, there was eye contact, but no verbal communication. This condition was included to help tease out confounding variables such as levels of excitement and attention associated with being face-to-face with a communication partner and other variables contingent on phonation.

4. Conversation: Dyad members were engaged in a natural, face-to-face conversation or interaction.

Because of the natural situation of this study, the best attempt was made to include multiple occurrences of all of the above conditions within the designated recording time with each dyad. These conditions were not imposed on the subjects, rather the mother and the child were allowed to interact naturally and segments of the session were later assigned to the above conditions. Unfortunately, opportunities for multiple trials for each condition, or opportunities for the condition number 3, did not always occur. Breathing patterns for most of the above conditions were captured multiple times during the course of the test session.

The nested variables for this study were based on the types of communicative events that could be used by the child:

1. non-verbal communication (e.g., nods, shakes of the head, pointing) that were either
    a. contingent to what the mother said or asked
    b. non-contingent to what the mother said or asked;
2. vocalizations that were not words (e.g., whimpers, grunts, cries);
3. word utterances that were either
    a. contingent to what the mother said or asked
    b. non-contingent to what the mother said or asked
4. breath holds
5. turn-taking events (e.g., vocalizations, taking a turn with a toy, responding to a request).

This set of nested variables was used in an informal manner; they were coded and quantified throughout the course of data analysis to better understand the presence or absence of entrainment (Boliek et al., 1996; Boliek et al., 1997).

The test environment was set up to look natural in order to minimize distractions and to encourage the mother and child to feel at ease. The room had adequate lighting and was decorated to resemble a regular play area at home. A natural environment in which the interaction could take place was highly important, even if the decorative aspect of the environment differed from dyad to dyad. Figure 7 shows how the interaction was set up.

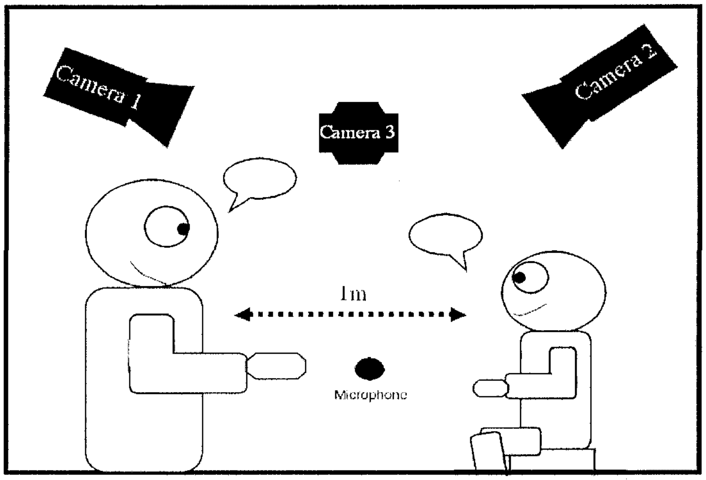


Figure 7. Mother-child, face-to-face interaction.

During the experimental conditions, measures of respiration, video and audio signals were acquired from each member of the dyad. These measurements were used to isolate features hypothesized to be associated with entrainment in naturally occurring, mother-child, face-to-face interactions such as: (a) respiratory patterns associated with ventilation (e.g., medullar respiratory control centers), (b) audio signals, and (c) patterns associated with the exogenous features of communicative and play events.

Because the data acquisition yielded non-alterable biological waveforms, experimenter bias was controlled for and objective analysis was carried out by the computer. Noisy (e.g., clipped signals) or unnatural signals (e.g., movement) were eliminated when the researchers involved in the data analysis were in agreement. Examples of what noisy or unnatural signals might look like are shown in Figure 8.

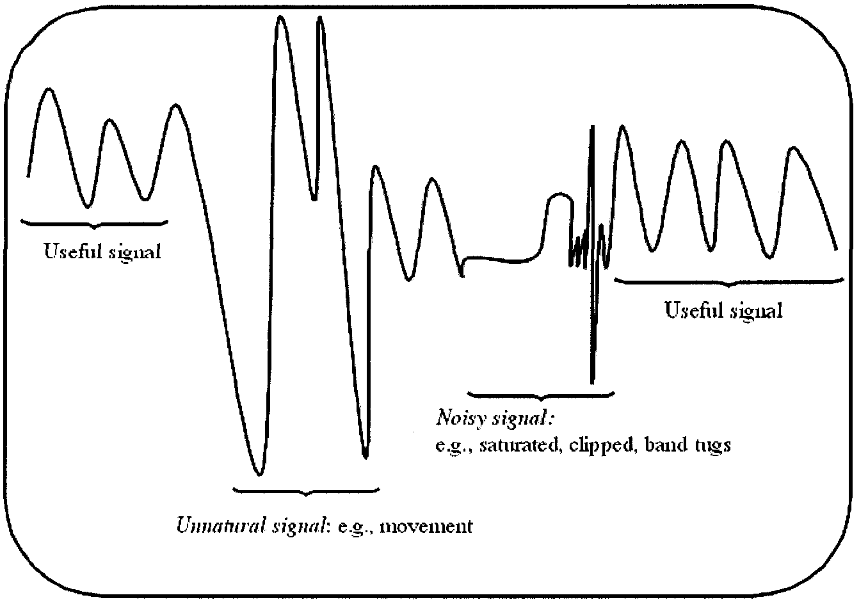


Figure 8. Examples of used and unused signal.

Three different observers (two Speech and Language Pathology students and a person naïve to the field of Speech and Language Pathology) watched the videotaped interactions for each dyad (camera 3 signals). They each noted the time segments, based on their own individual perceptions, in which communication involving both partners attending to one another took place. Typically, utterances in a sequence of turn-taking events, attending to the same objects and occasional eye contact were behaviours used to delineate an interaction. According to Warreyn, Herbert, and De Groote (2005), the best opportunity for observing social, engaged interaction from a child with ASD is when they interact with their mothers. The video segments which all three viewers had selected to be a significant interaction, where both members of the dyad were attending, were highlighted. Interactions from this pool were then chosen for data analysis based on (a) duration (longer segments were preferred over shorter ones), (b) quality of signal (e.g., segments with clipped or saturated signals were not preferred) and (c) absence of other variables (e.g., movement, drinking, eating, other persons involved in the interaction). It should be noted here that the observers were not blind to diagnosis.

# PROCEDURE

## Pre-experimental Phase

### *Experimental group*

Participation was solicited through poster advertisements provided to caregivers of children receiving services through Family Linkages. Interested caregivers were given the appropriate contact information. Upon first contact, mothers were provided with a description of the qualifications for participation in the study and a summary of the purpose and procedures. If mothers continued to show interest and qualified for the study, Dr. Carol Boliek and Gabriela Constantinescu requested a home visit. Home visits were an opportunity for mothers to ask more questions about the study and fill out the Parent Questionnaire (adapted from Norman, 1963) and Questionnaire ASD1 (see Appendix A and B respectively). Questionnaire ASD1 was aimed at finding out more information regarding the child's diagnosis, temperament and the nature of the interactions between the mother and child. This questionnaire also served as a guideline for the researchers to better accommodate the needs of the child during the laboratory visit. An Information Letter and a Consent Form were provided at this time. Lastly, children with ASD were provided with a pair of soft cloth bands and a soft face-mask prior to the testing day so that they might get used to wearing them at home. All mothers however reported that they had not used them with their children prior to the day of the experiment. Dates and times were then scheduled for each individual dyad to meet at Corbett Hall to begin the experimental phase. The experiment was then set up keeping in mind each child's preferences for reinforcement, stimuli and time of fatigue.

### *Control group*

Typically developing children and their mothers were recruited by word of mouth and were selected to match the chronological age (by a difference of no more than 7 months) and gender of the children in the experimental group. The participants in the control group were given the Parent Questionnaire, the Information Letter and the Consent Form during the experimental phase, at Corbett Hall.

### Experimental Phase

During this phase, mothers were reminded again on what the experiment involved. The height, weight and age of the children and their mothers were recorded. Mothers were then fitted with the transduction bands from the Respitrace on their ribcage and abdomen as described earlier. Mothers were then instructed on how to place the same type of bands on their children. After both members of the dyad were connected to the data acquisition equipment and the signals were reset and calibrated, they engaged in a warm-up activity of their choice (e.g., talking, holding, playing). The mothers were then told to engage their child's attention and communicate with their child as they typically would, this time without touching (Conversation, condition 4). Once enough instances of communicative exchanges were observed, the mothers were asked to take part in the rest of the conditions (See below for details).

1. Tidal Breathing (Condition 1) – Quiet Breathing Samples

Following calibration of the equipment, quiet breathing samples were obtained from the child and the mother separately. The mother and the child were asked to sit quietly and an effort was made so that their attention was not intentionally captured by another person or by an object. Other persons present in the room were asked to be quiet to eliminate the possibility that the subjects might be listening and therefore entraining to them.

2. Conversation (Condition 4) – Child-Mother Dyadic Communication

Following calibration of the equipment and the warm-up period, the mother and child were asked to interact as they would at home. Interactions were not scripted in any way. Mothers were asked to remain approximately 1 meter apart from their child and avoid physical contact during this time.

3. Independent activity and Face-to-face, no speech (Conditions 2 & 3)

An attempt was made to collect breath groups for segments that fit the criteria for the following conditions:

a) Engaged with an inanimate object

Again, breathing patterns were collected while the child was playing with a toy and the mother was looking at pictures from a magazine. Segments where the mothers appeared to be reading the magazine were excluded; perturbations in the breathing patterns have been observed during nonvocalized speech tasks such as silent reading (Conrad & Schönle, 1979).

b) Face-to-face, not vocalizing

Segments selected to fit this description included eye contact, but no touching or vocalizing between the mother and the child. This was set up as a 'staring contest' between the mother and the child in control groups. In experimental groups, any naturally occurring instances of this behaviour were saved and compiled.

After an attempt was made for the inclusion of all conditions, the mother's isovolume and lung volume measures were recorded. Capturing the child's lung volume measures was attempted, but discontinued if the child was not comfortable with the face-mask, as was often the case with children with ASD, and this value was then estimated from the child's height and weight. For all the experimental dyads, a third person was present (father, aide) to help ensure that the child was at ease, that the child had access to toys or that the child could be disconnected from the equipment for break periods. When possible, a third person was then present for the control dyads as well, but asked not to interact with either of the mother or the child. Times of the desired conditions were recorded on-line and again from the video recording, by a total of three different observers. The communication exchange used for the conversation condition was taken where there was unanimous agreement between the three recorders, as explained in the *Design*.

## Analysis

Selected physiological signals were digitized (250 cycles/second) along with audio (40,000 cycles/second) and video signals (30 frames/second). Signals were calibrated for volume of air against a piston syringe and using isovolumes for chest wall movements. Lung volume, as estimated from the chest wall movement, was then calibrated against volume assessed at the airway opening (see Appendix C for details on the calibration process). Digitized rib cage and abdomen signals yielded measures of inspiratory and expiratory duration (in seconds) and volume of air inhaled or exhaled as a factor of time (in slope of the waveforms) during baseline and experimental conditions, as explained below. In addition, as mentioned earlier, communicative category (e.g., non-verbal communication, contingent or non-contingent; non-word vocalizations; word utterances, contingent or non-contingent; breath holds; and turn-taking events were also quantified) (Boliek, et al., 1996; Boliek, et al., 1997).

### *Analysis A*

The exact same time segments used in this analysis were used in subsequent analyses as well. The first level of data analysis determined if one or more of the timing and volume measures could be used to differentiate respiratory behaviour across conditions. To my knowledge, McFarland (2001) conducted the only previous investigation that employed quantitative comparisons of respiratory timing and respiratory cycle duration to conversational synchrony. My analysis went one step further by including calibrated lung volume, averaged timing measures and grand-average waveforms for both inspiratory and expiratory portions of breathing cycle. This same approach was used by Boliek et al. (2006a; 2006b; 2003). In this analysis, LabView software (National Instruments) was used to display the abdomen, rib cage, lung volume and voice signals for both the child and the mother simultaneously, and save segments of the session for each condition. The segments were then converted into Excel spreadsheets containing lung volume and voice channel signals. Each second of video was translated into 250 spreadsheet cells. For the conversation condition (Condition 4), a composite spreadsheet was created and each cell was coded based on whether (a) the child was speaking at the time, (b) the mother was speaking, (c) no one was speaking, or (d) they were both speaking at the same time. Coding the conversation segments in this fashion isolated the times in which the subject was speaking from those in which he/she was listening to his/her communication partner. As mentioned earlier, in the presence of entrainment, one would expect the breathing patterns during listening portions of the segment to be more analogous to speech breathing and less so to tidal breathing patterns (McFarland, 2001; Boliek et al., 2006a; 2006b; 2003).

Once the samples for all of the conditions were acquired and digitized, the waveforms were analyzed using MATLAB software code. First, the waveforms were passed through a filter to remove high frequency noise. After filtering, linear trends due to drifts and shifts in the signal were removed. All inspiration waveforms were pooled and all expiration waveforms were pooled within each condition, for each individual subject in a given dyad. Unusual waveforms that could be seen as outliers and not biomechanically possible (i.e., waveforms that were too short or too long in duration) were removed. The code in the program excluded any 'inspirations' and 'expirations' shorter than 200ms for both adult and child participants; anything that short in duration could not be a true behaviour of a human system. Using the same rationale, the code was also used to exclude 'inspirations' longer than 3 seconds for adults and 2 seconds for children across all conditions. 'Expirations' longer than 3 seconds for adults and 2 seconds for children participants were also excluded, but only in the tidal breathing condition. These parameters were chosen based on the norms developed by Beckerman, Brouillete & Hunt (1992). The latter step was applied solely to tidal breathing conditions because the expiratory limb was expected to show the most perturbation in subsequent conditions. As a result, no restrictions were made to the expiratory limb of all other conditions because they were expected to vary. The program then created mean and standard deviation inspiration and expiration waveforms, as well as composite graphs (mean inspiration waveform attached to the mean expiration waveform to yield a composite breath group). This analysis approach was previously used by Boliek et al. (2006a; 2006b). Figure 9 shows hypothetical samples of inspiratory waveforms gathered from one subject in a given condition and how they were compiled into a single mean waveform and two standard deviation waveforms. The mean signals in each condition were then compared in terms of their general slopes and significant differences as indicated by the standard deviation of each array. Composite waveforms, constructed from mean inspiratory and mean expiratory waveforms, served to represent the signature waveform for each condition for each subject. Using these waveforms, the overall effects of a given condition on the respiratory pattern could be compared. Composite waveforms were analyzed for differences in general symmetry and shape.

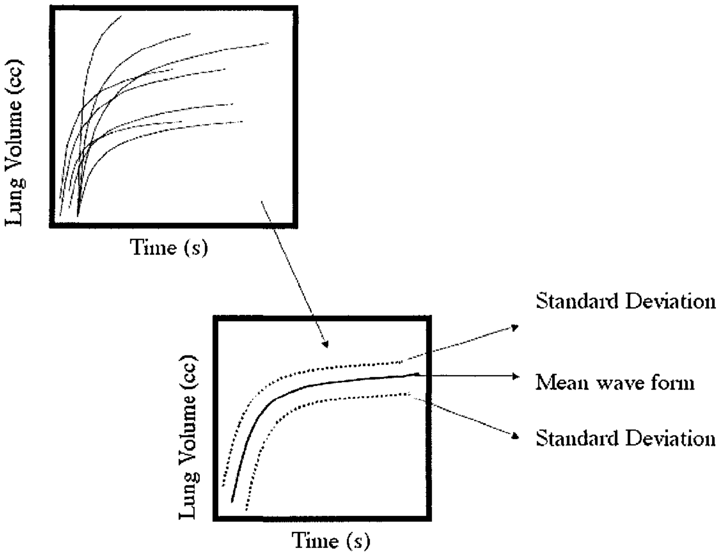


Figure 9. Hypothetical inspiratory waveforms converted into one mean waveform and 2 standard deviation waveforms.

In a subsequent analysis, the above waveforms were normalized for time and volume; each wavelength, regardless of duration, had an equal opportunity to influence the mean. This was done by taking the maximum value, in any condition, on the y and x axes and representing all other values as a percent of that maximum value. Waveforms were then analyzed again for qualitative differences by looking at the general shape of the graphs.

### *Analysis B*

The second level of analysis looked at the means and standard deviations of inspiratory and expiratory times across conditions and for each subject. Results from this analysis were used to identify perturbations in breathing patterns from baseline during face-to-face interactions and to examine the results in a similar fashion as McFarland (2001).

Three different methods were employed in the present study to obtain evidence of perturbation in breathing patterns. Researchers also examined differences in breathing patterns from rest breathing on either side of the respiratory cycle (inspiratory and expiratory limbs alone, and the combined cycle). The observations made in *Analyses A* and *B* were merged in Table 20 of the *Results* for ease of viewing and to serve as a summary of the observations in this study. The relative strength of entrainment was judged to be contingent on a convergence of observations of perturbation in breathing patterns relative to tidal breathing from multiple methods of analyses.

# RESULTS

The results below were organized in a case study approach; each dyad was individually described and each experimental dyad was compared only to its control dyad. This was appropriate due to the small number of subjects and the great variability in the interaction styles and level of functioning between the children in the experimental group. Each control dyad was described along with its corresponding experimental dyad to create a 'group', for a total of 3 groups studied. Within each group, the control dyad was analyzed first to gain a better understanding of what was typical of a face-to-face interaction between a child of that particular age and sex and his/her mother. The experimental dyad was then analyzed with respect to the matched control dyad. Within a dyad, the mother's breathing patterns were described first, followed by the child's.

It should be noted that only two dyads (dyad #1 and dyad #5, both control dyads) were able to successfully fulfill the face-to-face, no speech condition, as defined in the *Design*. As a result, this condition was analyzed separately in the composite waveforms. Furthermore, some acquired segments contained a saturated abdomen signal. However, these segments were still used in the analyses; the contribution made by the rib cage usually represents about 80% of the total lung volume (Hixon, Goldman, & Mead, 1973). When the total volume from the above segments was compared to the predicted tidal volumes for those subjects, the values were always within 20% of one another. In one instance, the rib cage signal was saturated. This condition was still used in the analyses, but conclusions were drawn in light of this fact (inspiratory and expiratory durations, shown in *Analysis B*, were not affected). Table 2 summarizes the information of all participants in this study.

Table 2. General Information of the Subjects in this Study.

| | **Mother** | **Child** | **Mother** | **Child** |
|---|---|---|---|---|
| **Group 1** | **Control Dyad** | | **Experimental Dyad** | |
| Age at Time of Experiment | 37 yrs | 3 yrs -4 mos | 30 yrs | 3 yrs -11 mos |
| Weight (kg) | 68.1 | 17.26 | 61.29 | 20.43 |
| Height (cm) | 180.34 | 106.5 | 162.56 | 110.00 |
| **Group 2** | **Control Dyad** | | **Experimental Dyad** | |
| Age at Time of Experiment | 30 yrs | 2 yrs -7 mos | 27 yrs | 2 yrs -11 mos |
| Weight (kg) | 105 | 16 | 81.72 | 18.16 |
| Height (cm) | 167.64 | 95 | 160.02 | 100.97 |
| **Group 3** | **Control Dyad** | | **Experimental Dyad** | |
| Age at Time of Experiment | 35 yrs | 4 yrs -8 mos | 30 yrs | 4 yrs –11 mos |
| Weight (kg) | 54.48 | 16.34 | 95.34 | 40 |
| Height (cm) | 154.94 | 112 | 157.48 | 106 |

## Group #1

### *Dyad #1: Typically Developing Child*

The mother in this dyad described herself as somewhat talkative, open and sociable in the Parent Questionnaire. The child was 3 years and 4 months at the time of the experiment, 7 months younger than his experimental counterpart. Table 2 summarizes the details of this dyad. There was no third person seated beside this child in the session.

*Condition Time-Segment Description*

Table 3 summarizes the number of usable inspirations and expirations for each condition and subject. As mentioned in the *Design*, only useful signal was used; noisy (e.g., clipped signals) or unnatural signal (e.g., movement) was eliminated when the three researchers involved in the data analysis were in agreement. Table 3 also displays the respective durations of each chosen segment.

Table 3. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 23 | 10 | 11 | 28 | 15 | 16 |
| Independent Activity | 48 | 16 | 17 | 48 | 19 | 20 |
| Face-to-face, no speech | 23 | 10 | 14 | 23 | 10 | 11 |
| Listening | 48 | 5 | 3 | 48 | 5 | 3 |
| Talking | | 7 | 4 | | 7 | 5 |

Below follows a brief description of what happened during each condition.

*Tidal breathing.*

During this segment, the mother watched other people in the room and she had no eye contact with her child. The child did the same during his segment.

*Independent activity.*

The segments chosen for this condition were taken simultaneously for both the mother and the child. They were looking at their respective books and there was no talking. Unfortunately, the mother's rib cage signal was saturated for this condition but the abdomen signal produced a reliable one.

*Face-to-face, no speech.*

The segments for this condition were again, happening simultaneously for both the mother and the child. The two were engaged in a staring contest.

*Conversation.*

During this interaction, the mother and her child were playing a pretend game, where each one controlled and spoke for a different toy animal. The toys were then having a conversation amongst themselves. As a result, there was no eye contact between the mother and the child in this conversation although the child displayed appropriate eye contact during other interactions in the recording. Table 4 summarizes the nested variables observed during these interactions.

Table 4. Communicative Events for the Conversation Segment Chosen:

| **Communicative Event** | | # Occurrences |
|---|---|---|
| Eye contact | | 0 |
| Non-verbal communication (nods, shakes of head, pointing) | | 0 |
| | Contingent | |
| | Non-contingent | |
| Non-word vocalizations | | 0 |
| | Contingent | |
| | Non-contingent | |
| Word utterances | | 12 |
| | Contingent | 12 |
| | Non-contingent | 0 |
| Turn-taking events | | 12 |
| Breath holds | | 0 |

*Quantitative Results*

*Analysis A.*

Below are the mean waveforms for both the mother and the child, for each condition (Fig. 10a). The scales for these graphs are all equal allowing for visual comparison against real volume. It should also be noted here that when the waveforms were filtered, their amplitudes were minimally diminished. This minute alteration can explain why some of the volumes were slightly smaller than expected given the subject's height and weight. This alteration affected all the data in the same way.

The inspiration and expiration waveforms were first analyzed separately; Boliek et al. (2006a; 2006b) have found that sometimes the adjustment made by each dyad member may happen on either the inspiratory or expiratory limb of the breath group, with the expiratory limb being the more common of the two to adjust during a perturbation. As mentioned in the *Analysis,* first the non- time and volume normalized waveforms were analyzed for differences in slope, followed by the normalized waveforms which were analyzed for differences in their overall shape (Boliek, et al., 2006a; 2006b; 2003). When looking at the non- time and volume normalized waveforms for the mother, the listening condition has a different slope from that of rest breathing. In the inspiratory limb, its slope is similar to that of the independent activity waveform; in the expiratory limb, it is similar to all other conditions except for rest breathing. The listening and talking waveforms both shorten in duration (duration is analyzed in more detail in *Analysis B*). When looking at the mother's time and volume normalized waveforms, the waveform for the talking condition appears to be markedly different from the ones in all other conditions. This difference is only apparent in the inspiratory limb however. Turning to the child's breathing patterns, the non- time and volume normalized waveforms reveal no significant difference between any of the conditions. It can be noted that the listening and talking conditions have slightly steeper slopes for both inspiration and expiration, but it is difficult to say whether this difference is substantial. The time and volume normalized graphs tell a different story however. In both the inspiration and expiration, the listening condition has a markedly different waveform from all the other conditions. When interpreting the observations above, it should also be noted again that (1) only a small number of breaths were available for analysis for the listening and talking conditions for the members of this dyad, (2) the mother and the child did not have eye contact during their interaction and (3) that the segment used for the mother's independent activity condition had a saturated signal (i.e., the slope is not entirely representative of this condition).

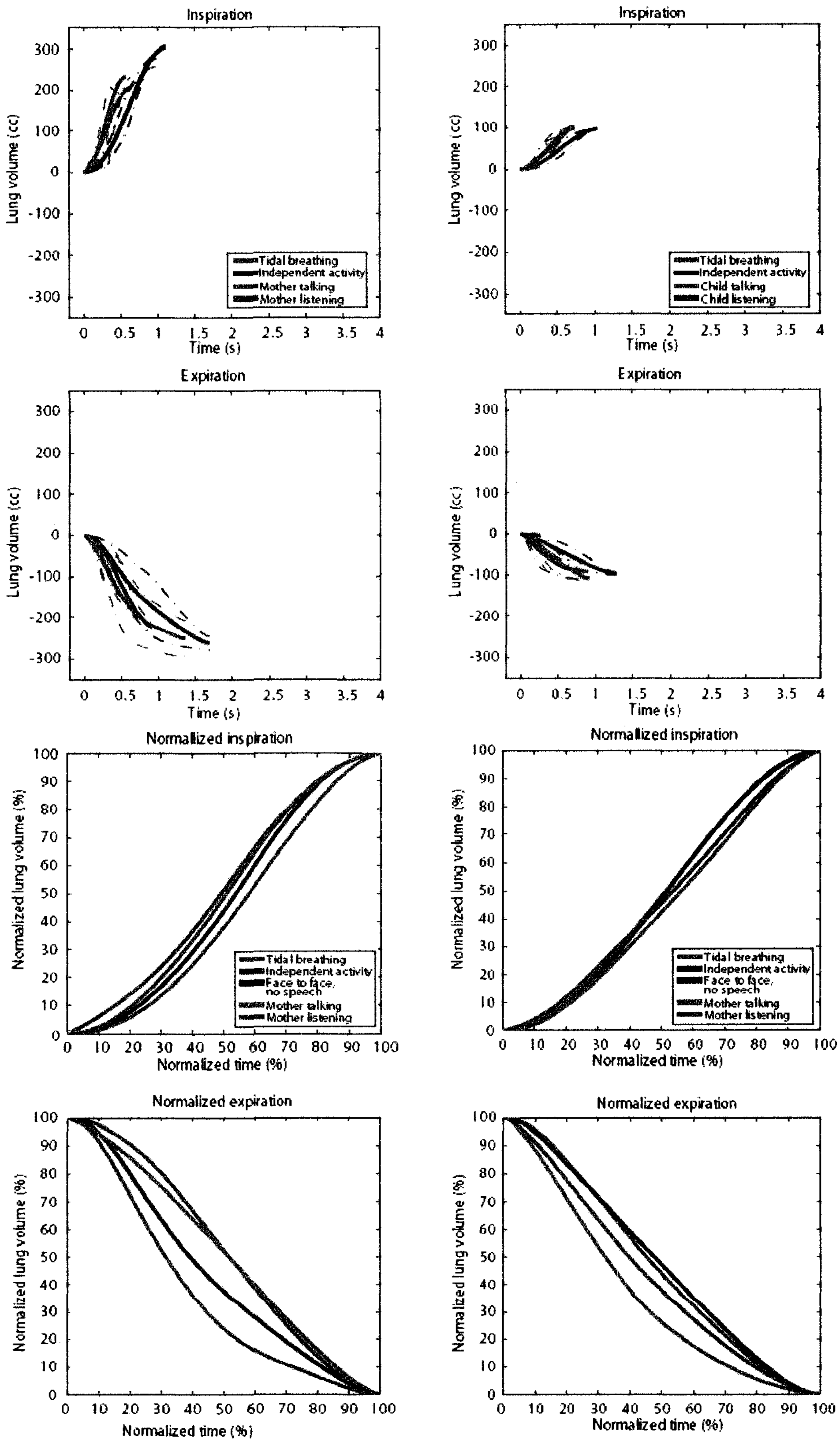


Fig 10a. Non-time and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

## Dyad #2: Child with ASD

From results on the Parent Questionnaire, the mother in this dyad described herself as an extremely social, open and talkative individual. The child was 3 years 11 months of age at the time of the experiment. The mother reported that he had been diagnosed with ASD at 2 years and 6 months of age. His mother reported that he could attend briefly to an object of interest, that he could point or that he sometimes used her own hand to point. This child was verbal; beside some non-word vocalizations, he could also say words and imitated many words and phrases. See table 2 for a summary of this dyad's details.

In the interactions observed by the researchers, the child could make eye contact and his attention could be sustained for very brief periods of time. He could vocalize, but did not say any recognizable words apart from "water" and "milk" which were reported by his mother. When given choices, he was able to point to the one he desired. In the absence of choices, he was also able to make requests (e.g., coke) through sign, gestures or vocalizations. Sometimes his turns within a conversation were repetitions or echolalia. The child showed frustration or discontent by crying, turning away or walking towards the door. He was very sensitive about having his face touched, but was okay wearing the Respitrace bands. The mother was skilled at giving her child enough time to make requests, at calming him down and at engaging him. She was very responsive to the child during the interaction. The child's father was also present during the session as a background support person, ensuring that the child was at ease, that toys were within reach and the child could easily be unhooked from the equipment if needed. The mother also commented that the child was relaxed during this experiment.

### *Condition Time-Segment Description*

Table 5 summarizes the number of selected inspirations and expirations for each condition and subject as well as the respective durations of the segments chosen for each condition.

Table 5. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 45 | 18 | 19 | 23 | 13 | 14 |
| Independent Activity | 66 | 22 | 24 | 83 | 34 | 35 |
| Face-to-face, no speech | NA | | | NA | | |
| Listening | 95 | 2 | 3 | 95 | 7 | 5 |
| Talking | | 6 | 7 | | 3 | 3 |

Below follows a brief description of what happened during each condition.

#### *Tidal breathing.*

The segments chosen to represent this condition were instances when the mother and the child were not facing one another and when no one was talking.

#### *Independent activity.*

The segments chosen for this condition did not occur simultaneously for the mother and the child. An attempt was made to capture the best instances of this condition for both mother and child and this did not always happen at the same time for both of them. The mother flipped through the pages of a magazine while the child played with a pop bottle and appeared to be very focused on it.

### *Face-to-face, no speech.*

Breathing waveforms for this condition were recorded during the same time segment for both the mother and the child. However, due to movement, the breath groups chosen for the two did not occur simultaneously (i.e., the child's breath groups occurred at the beginning of the file and the mother's at the end). Because this did not fit the criteria for this condition, this segment was not used in the analysis.

### *Conversation.*

During this interaction, the mother asked her child to make a choice between juice and Coke. The child looked up at the mother before making an utterance, was able to engage in joint attention and made a choice. The mother used simple language, repeated the question and also imitated the sound and prosody of her child's utterance as part of her turn. Table 6 summarizes the nested variables observed during this interaction.

Table 6. Communicative Events for the Conversation Segment Chosen:

| **Communicative Event** | | # Occurrences |
|---|---|---|
| Eye contact | | 4 |
| Non-verbal communication (nods, shakes of head, pointing) | | 0 |
| | Contingent | |
| | Non-contingent | |
| Non-word vocalizations | | 3 |
| | Contingent | 2 |
| | Non-contingent | 1 |
| Word utterances | | 0 |
| | Contingents | |
| | Non-contingent | |
| Turn-taking events | | 3 |
| Breath holds | | 0 |

### *Quantitative Results*

#### *Analysis A.*

Figure 10b shows the mean waveforms for both the mother and the child, for each condition. When looking at the non- time and volume normalized waveforms for the mother, no noteworthy difference appears between the conditions; although the listening and talking waveforms appear close together, they are similar in slope to the waveforms of other conditions. The time and volume normalized waveforms again show a different pattern: on the inspiratory limb, talking and listening are different from rest breathing. This difference is even more pronounced on the expiratory limb. The non- time and volume normalized waveforms for the child reveal no notable differences between the conditions, neither in the inspiratory limb nor the expiratory limb. The time and volume normalized waveforms for the inspiratory limb reveal the same conclusions. However, the time and volume normalized waveforms for the expiratory limb show a marked difference between the talking condition and rest breathing and a small difference between the listening condition and rest breathing. Again, care should be taken when interpreting these results, as the number of available breaths for the listening and talking conditions was small.

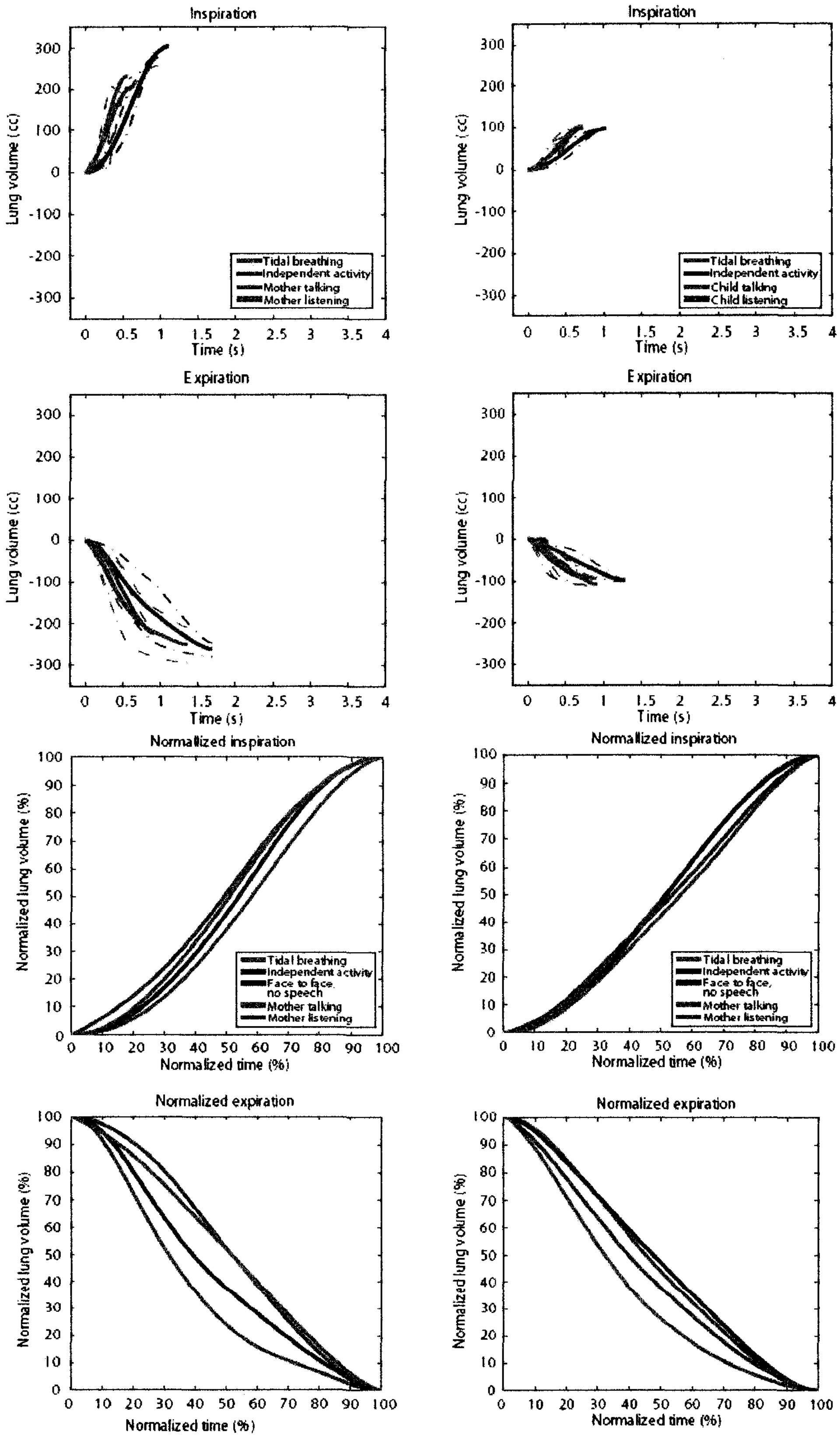


Figure 10b. Non-time and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

The composite mean respiratory waveform (mean inspiratory waveform plus mean expiratory waveform) were compared for each condition as well (Fig. 10c, d). As mentioned above, these waveforms were used to compare the characterizing respiratory behaviour associated with each condition. For both dyads in this group, the tidal breathing and independent activity waveforms look similar in shape and duration (2 seconds or longer). In the control dyad, the mother shortens the duration of her cycles and breathes in less air when listening to her child. The child also shortens his cycle duration during the listening condition. His volume intake does not change from tidal breathing, but this is expected since the mother's volume intake when talking is already around 100ccs which is near the child's ventilatory volume. A similar pattern is seen for the mother in the experimental condition. However, her child does not exhibit this change in cycle duration when listening to his mother.

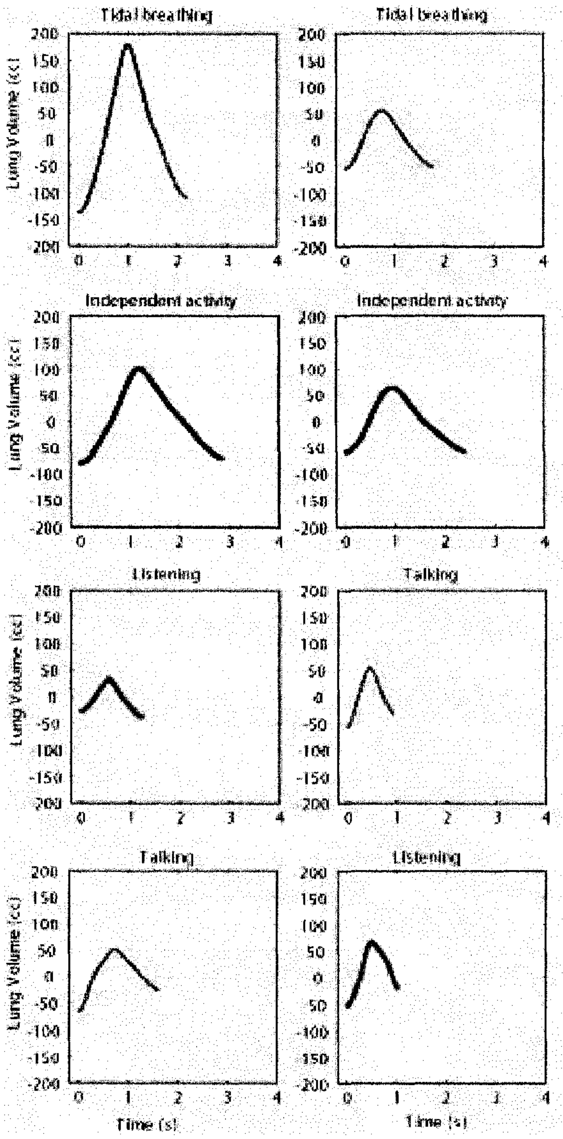


Figure 10c. Composite waveforms for the control dyad in this group (mother, child), for all conditions.

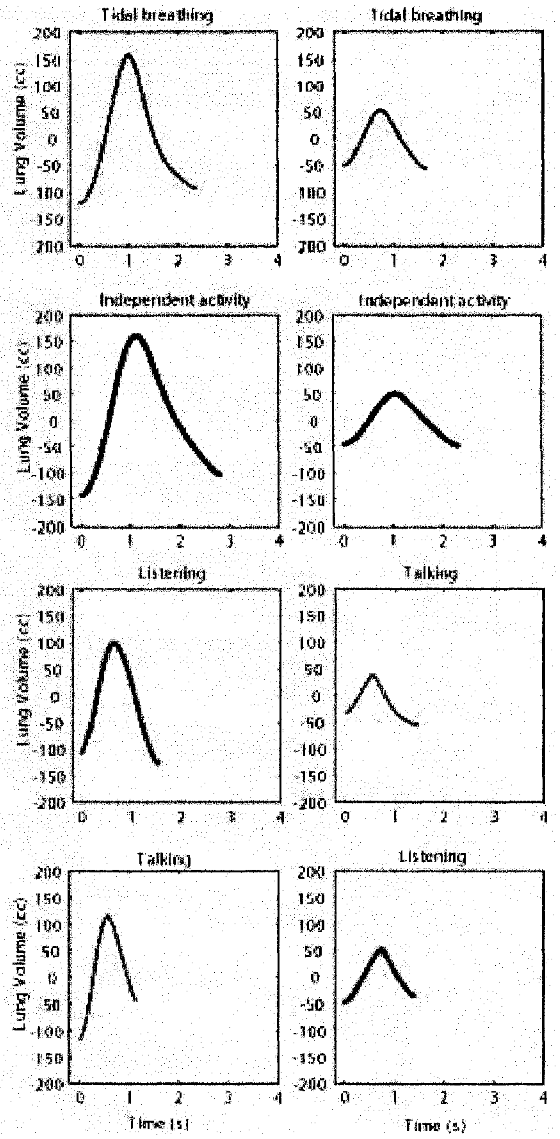


Figure 10d. Composite waveforms for the experimental dyad in this group (mother, child), for all conditions.

## Group #2

### *Dyad #3: Typically Developing Child*

The mother in this dyad described herself as fairly talkative and sociable, and very open in the Parent Questionnaire. The child was 2 years and 7 months at the time of the experiment, 4 months younger than her experimental counterpart. She was easily engaged by her mother and had a great disposition throughout the session. The child's father sat beside her, but was not involved. See table 2 for a summary of this dyad's details.

*Condition Time-Segment Description*

Table 7 summarizes the number of selected inspirations and expirations for each condition and subject as well as the respective durations of the segments chosen for each condition.

Table 7. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 51 | 12 | 11 | 5 | 10 | 11 |
| Independent Activity | 42 | 10 | 11 | 20 | 10 | 10 |
| Face-to-face, no speech | NA | | | NA | | |
| Listening | 82 | 8 | 8 | 82 | 13 | 12 |
| Talking | | 8 | 9 | | 7 | 4 |

Below follows a brief description of what happened during each condition.

*Tidal breathing.*

During the mother's segment, no one talked and there was no eye contact between the child and the mother. During the child's segment, her parents talked to one another quietly, but she appeared not to attend to them because she was not facing them or trying to interject. During this segment some of the breathing signals were not ideal but useable for analysis. For example during part of the sample timing and volume estimates had to be obtained from the abdomen signal only.

*Independent activity.*

During her segment, the mother skimmed through the pictures of a magazine and the child made one or two small vocalizations to her father during the mother's segment. The child was quiet and her attention appeared to be captured by a box of crayons she was holding.

*Face-to-face, no speech.*

Although this condition was intentionally attempted through a staring contest and the researcher also looked for instances of it occurring naturally in the session, no segments were found.

*Conversation.*

Two segments were selected for this condition. During both segments, the mother and the child talked about barnyard animal sounds in a book. Table 8 summarizes the nested variables observed in these interactions.

Table 8. Communicative Events for the Conversation Segment Chosen:

| | | Segment #1 | Segment #2 |
|---|---|---|---|
| **Communicative Event** | | # Occurrences | # Occurrences |
| Eye contact | | 5 | 3 |
| Non-verbal communication (nods, shakes of head, pointing) | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Non-word vocalizations | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Word utterances | | 6 | 10 |
| | Contingent | 6 | 10 |
| | Non-contingent | 0 | 0 |
| Turn-taking events | | 6 | 10 |
| Breath holds | | 0 | 0 |

### *Quantitative Results*

*Analysis A.*

The non- time and volume normalized waveforms of the mother (Fig. 11a) show a nice difference in the inspiratory limb: the talking and listening conditions have a similar slope to one another, but different from those of the tidal breathing and independent activity. No such difference is apparent in the expiratory limb. The mother's time and volume normalized waveforms (Fig. 11a) show the opposite trend: there is no observable difference between the conditions in the inspiratory limb, but on the expiratory limb, talking and listening are somewhat different from rest breathing. The child's non- time and volume normalized waveforms (Fig. 11a) show no remarkable difference between any of the conditions (note: the standard deviations of these waveforms were not shown for ease of viewing and because the mean waveforms were very proximal). The time and volume normalized waveforms do not show a difference either (Fig. 11a). On the expiratory limb however, it is interesting to note that the waveform for tidal breathing and the one for listening are very similar in shape. Since the child's parents were talking in the background when the child's rest breathing segment was acquired, it is possible that the child might have been entraining to them.

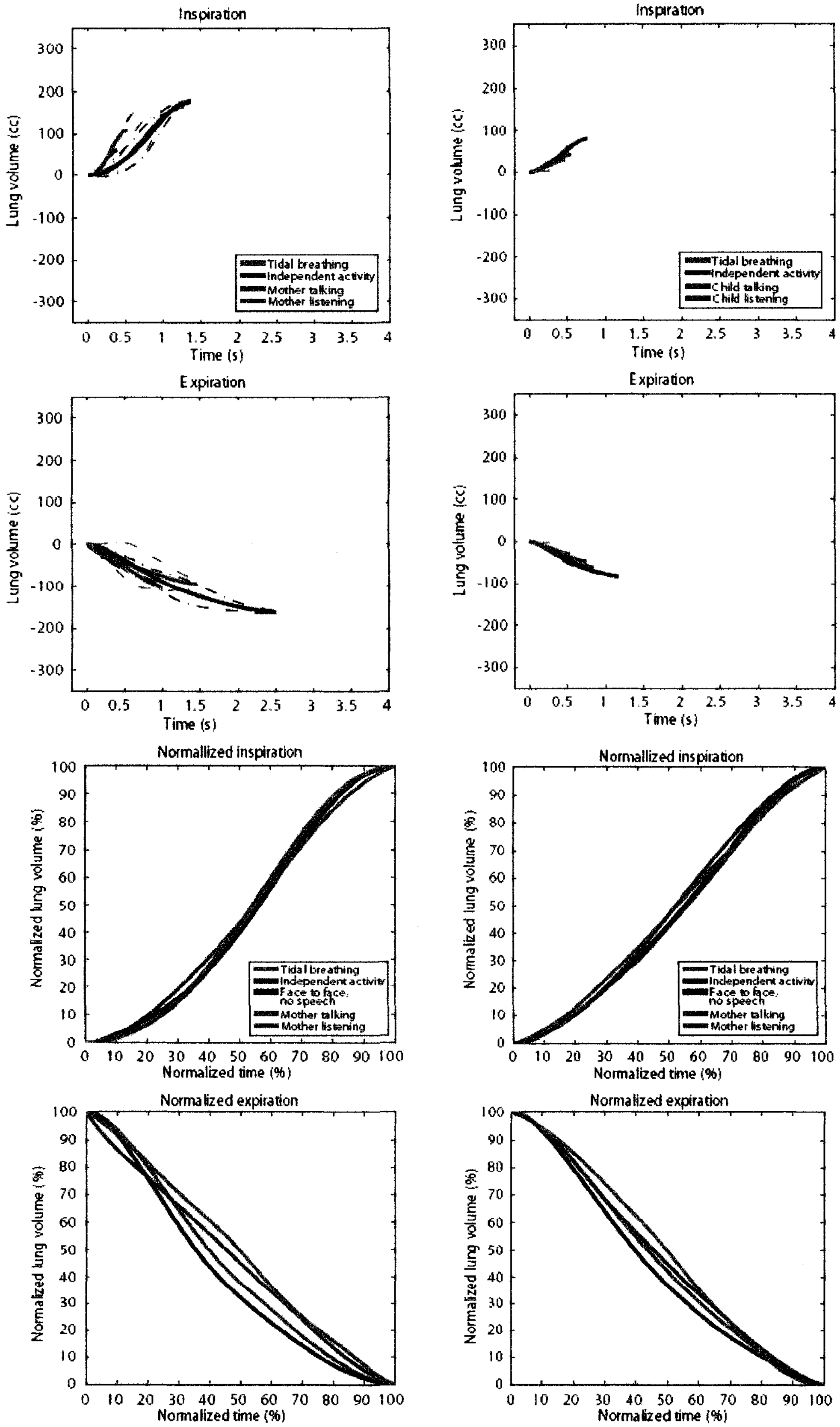


Figure 11a. Non-time and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

### *DYAD #4: Child with ASD*

The mother in this dyad rated herself to be very talkative, very open and somewhat sociable in the Parent Questionnaire. Her daughter was 2 years and 11 months at the time of the testing and she had been diagnosed with Mild Infantile Autism. The mother reported that her daughter could understand humor, different tones of voice and behaviours. The child was reported to use pictures or physically manipulate objects to request something. She could use some gestures, for example 'more'. Her mother reported that her child could say "ma" for 'mama' and "pa" for 'papa' and that she enjoyed singing. Her mother also mentioned her child responded well to choices and was easy to engage intermittently while watching television. See table 2 for a summary of this dyad's details.

During the experiment, the child was able to engage in joint attention, but had very few instances of eye contact. She was very vocal, but none of her utterances were words recognizable by the researcher. She was able to take turns in her vocalizations, but mostly vocalized continuously. She was observed to comply with her mother's requests (e.g., "Use two hands"). The mother was effective when engaging her child's attention using song, different toys and taking a turn after the child's utterances (e.g., child vocalized and mother commented, "Oh yes? Is that right?"). The mother also commented that the child was at ease during this experiment. This child wore a tight body suit under her clothes underneath which the bands were positioned. The child occasionally snacked on cheerios throughout the session to maintain her focus. Breathing during the swallows was not expected to affect the overall mean waveforms, as their frequency was very low (e.g., one swallow per sample). The child was also standing at different periods during the session, however, according to Hixon, Goldman

& Mead (1987, p.121), her overall breathing patterns should not be affected. The child's aide acted as the third person present during the session for background support.

*Condition Time-Segment Description*

Table 9 summarizes the number of selected inspirations and expirations for each condition and subject as well as the respective durations of the segments chosen for each condition.

Table 9. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 21 | 11 | 10 | 13 | 10 | 9 |
| Independent Activity | 62 | 18 | 17 | 22 | 11 | 13 |
| Face-to-face, no speech | NA | | | NA | | |
| Listening | 64 | 2 | 1 | 64 | 5 | 5 |
| Talking | | 3 | 5 | | 3 | 2 |

Below follows a brief description of what happened during each condition.

*Tidal Breathing.*

During the mother's tidal breathing segment she looked at the aide, the child was under the table during the mother's tidal breathing segment. The child looked at the floor, leaned on the aide and occasionally ate cheerios during her own segment.

*Independent activity.*

The segments for this condition were taken from about the same time in the interaction for both the mother and her child, but did not occur simultaneously. The television was on and the child vocalized occasionally (e.g., "mmm", "uuu") during both, the child's and the mother's segments. During her segment for this condition, the mother glanced at a magazine. During her segment, the child looked at a toy, she was standing and again, ate cheerios.

### *Face-to-face, no speech.*

During her segment, the mother looked in the direction of her child, but again there was no eye contact. Only one breath group for this condition made it difficult for any significant conclusion to be drawn so it was discarded. The child did not vocalize during her segment for this condition, but occasionally ate cheerios. There was no eye contact with her mother however, as the child looked off to the side and her mother talked to the aide. The television was on for both segments. Because these segments did not fit the criteria for this condition, they were not used in the analysis.

### *Conversation.*

Two segments were chosen for this condition. The television was off during both of these, as the child had become more comfortable to her surroundings by this point. During the first segment, the mother sang to her child and the child was standing and eating cheerios. The child's utterances resembled all the other utterances she made very frequently during the session, regardless of whether or not anyone was addressing her. She did however seem to respond by not talking, when her mother sang to her. During the second segment used for this condition, the mother talked to her child about juice and appeared to really engage her; the child's utterances were qualitatively different than the rest of the utterances she made during the session. They seemed more contingent and 'happy' in quality and she responded to her mother's requests (i.e., drank when asked to). Her mother also responded nicely to her child's utterances by attributing meaning to them (e.g., "Really H-?). Whereas this segment was the best behavioural example of the dyad's interaction, no useable respiratory data was obtained. Table 10 summarizes the nested variables observed in these time segments.

Table 10. Communicative Events for the Conversation Segments Chosen:

| | | Segment #1 | Segment #2 |
|---|---|---|---|
| **Communicative Event** | | # Occurrences | # Occurrences |
| Eye contact | | 0 | 1 |
| Non-verbal communication (nods, shakes of head, pointing) | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Non-word vocalizations | | 2 | 2 |
| | Contingent | 0 | 1? |
| | Non-contingent | 2 | 1 |
| Word utterances | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Turn-taking events | | 1 (quiets during song) | 2 (drinks; utterance) |
| Breath holds | | 1 | 0 |

### *Quantitative Results*

#### *Analysis A.*

Figure 11b shows the non- time and volume normalized and time and volume normalized waveforms for the mother and child in this dyad. The mother's inspiratory limb in the non- time and volume normalized waveforms shows no difference in slope between the listening, talking and tidal breathing conditions. However, the waveform for independent activity is markedly different from the rest of the conditions. On the expiratory limb, there is a difference in the slope of the talking and listening conditions from rest. The time and volume normalized waveforms show no difference between the conditions in inspiration, but a marked difference in the listening condition from rest in expiration. The independent activity waveform is different from rest in inspiration. The non- time and volume normalized and time and volume normalized waveforms appear to reveal the same trends. For the child, there is no remarkable difference between the conditions in either the inspiration or expiration when looking at the non- time and volume normalized waveforms. The time and volume normalized waveforms reveal a similar conclusion. However, the shape of the listening waveform in the expiratory limb has a very distinct and anomalous form. Again, it should be noted that some of the listening and talking conditions had a very small number of breath groups.

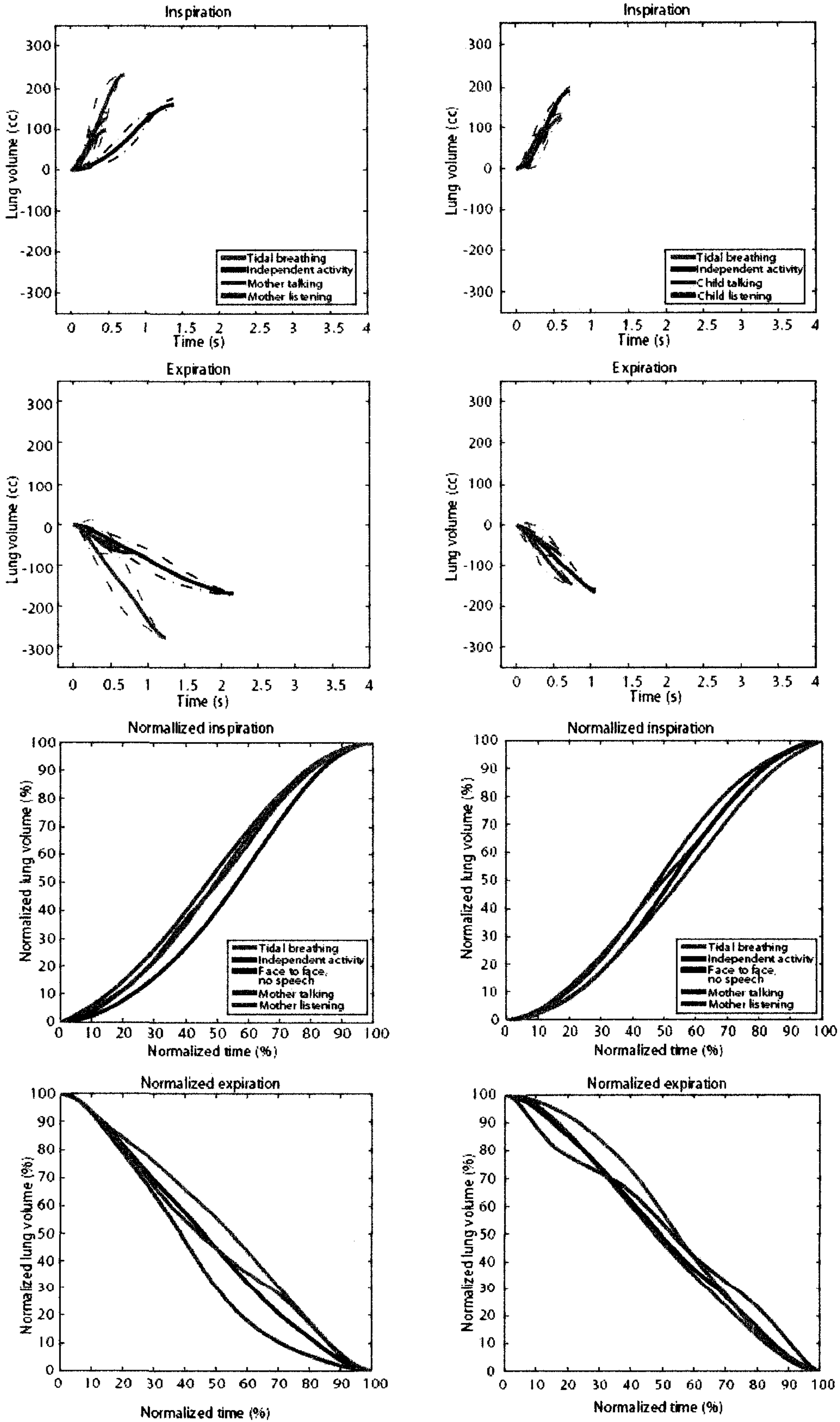


Figure 11b. Non-time and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

Figure 11c shows the composite waveforms in each condition for the control dyad, while figure 11d shows them for the experimental dyad. Both dyads show a similar waveform pattern during the tidal breathing and independent activity conditions. The two mothers appear to have longer exhalation durations during the latter condition. Both mothers also show a drastic decrease in mean breathing cycle duration and volume when they are listening to their children speak. The two children show a similar, yet less pronounced pattern when they are listening to their mothers. It is possible that the child in the control dyad was entraining to her parents during her 'tidal breathing' condition, leading to an unremarkable difference between her listening and rest breathing conditions.

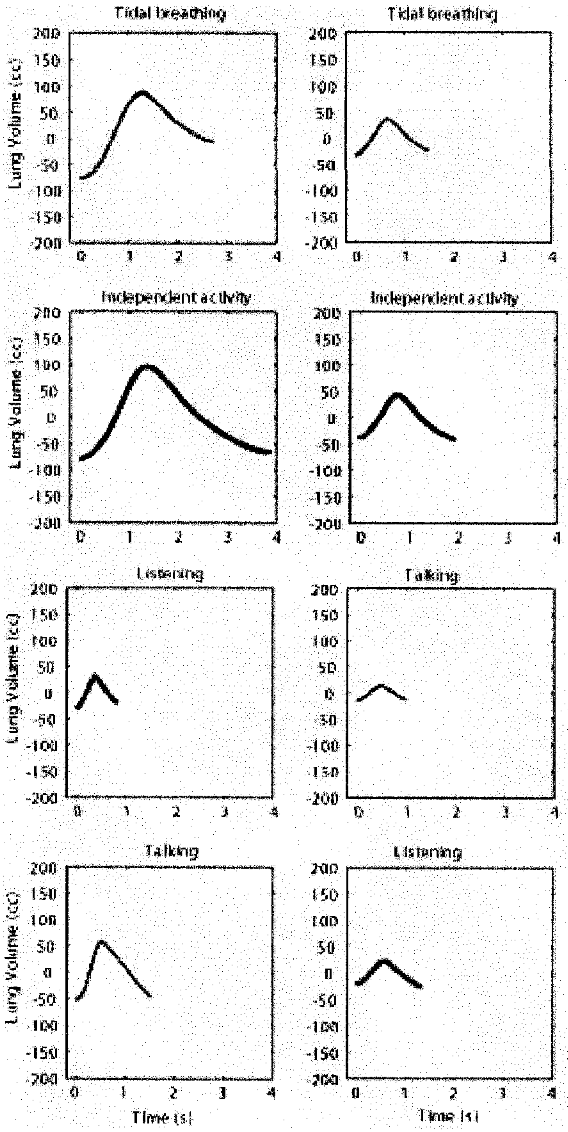


Figure 11c. Composite waveforms for the control dyad in this group (mother, child), for all conditions.

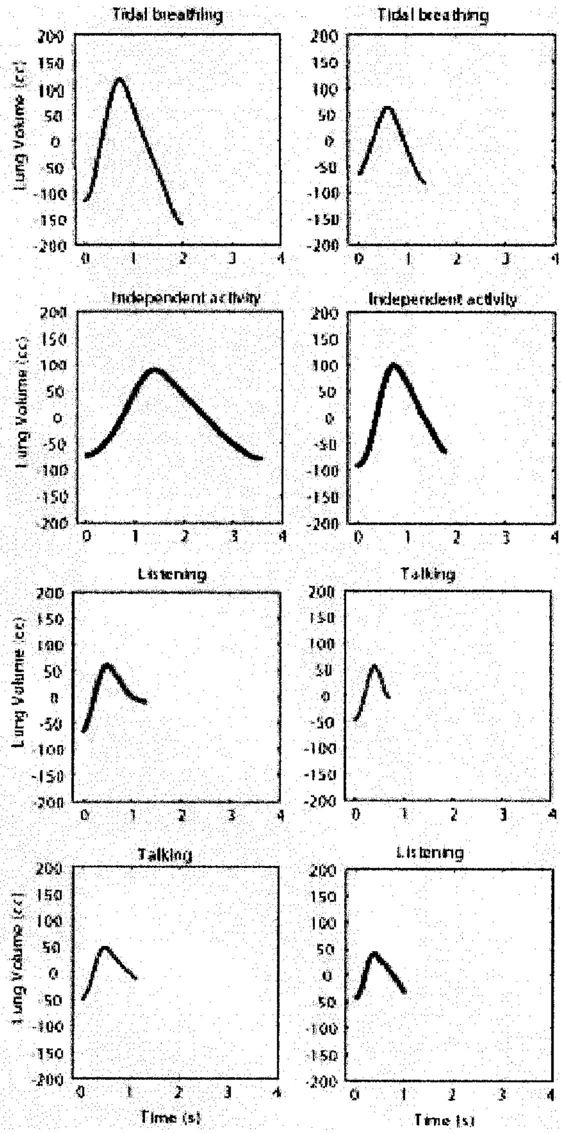


Figure 11d. Composite waveforms for the experimental dyad in this group (mother, child), for all conditions.

## Group #3

### *Dyad #5: Typically Developing Child*

The mother in this dyad judged herself to be somewhat talkative, very open and very sociable in the questionnaire. Her child was 4 years and 8 months at the time of the experiment, 3 months younger than his experimental counterpart. The child appeared very talkative, inquisitive and easily engaged. There was no third person seated beside this child in the session. See table 2 for a summary of this dyad's details.

*Condition Time-Segment Description*

Table 11 summarizes the number of selected inspirations and expirations for each condition and subject as well as the respective durations of the segments chosen for each condition.

Table 11. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 45 | 14 | 12 | 13 | 5 | 6 |
| Independent Activity | 51 | 16 | 16 | 51 | 20 | 20 |
| Face-to-face, no speech | 36 | 10 | 10 | 36 | 16 | 16 |
| Listening | 97 | 11 | 7 | 97 | 11 | 12 |
| Talking | | 8 | 8 | | 15 | 10 |

Below follows a brief description of what happened during each condition.

*Tidal breathing.*

During her segment, the mother was breathing in the mask, but the mask signals were not working at the time and so this segment was not used for calibration. During his segment, the child watched his mother and Dr. Boliek work on volume calibrations, but there was no eye contact between him and either his mother or Dr. Boliek.

*Independent activity.*

The mother's and child's segments for this condition were taken from the same time in the session (i.e., simultaneous independent activity). The mother flipped through the pictures in a magazine while the child did the same with a book. Both were quiet during this segment.

*Face-to-face, no speech.*

The mother's and child's segments for this condition were taken from the same time in the session (i.e., simultaneous activity). They were engaged in a staring contest and neither of them spoke during this segment.

*Conversation.*

Two segments were chosen for this condition. The mother and the child engaged in a conversation about toys, animals and trees. The child had eye contact with his mother on every utterance, he repeated his questions when interrupted and his sentences were high in complexity (i.e., up to 11 words in one sentence, use of 'but', 'and'). Table 12 summarizes the nested variables observed in these segments.

Table 12. Communicative Events for the Conversation Segment Chosen:

| | | Segment #1 | Segment #2 |
|---|---|---|---|
| **Communicative Event** | | # Occurrences | # Occurrences |
| Eye contact | | 13 | 9 |
| Non-verbal communication (nods, shakes of head, pointing) | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Non-word vocalizations | | 0 | 1 |
| | Contingent | | 1 |
| | Non-contingent | | 0 |
| Word utterances | | 14 | 8 |
| | Contingent | 14 | 8 |
| | Non-contingent | 0 | 0 |
| Turn-taking events | | 14 | 8 |
| Breath holds | | 0 | 0 |

*Quantitative Results*

*Analysis A.*

Figure 12a shows the non- time and volume normalized and time and volume normalized waveforms for the subjects in this dyad. In inspiration, the non- time and volume normalized waveforms for the mother show a similar slope between the listening and talking conditions; this slope is markedly different from tidal breathing. There is no obvious difference between the conditions on the expiratory limb. The time and volume normalized inspiratory waveforms show a slight difference in the shape of the talking waveform from the rest of the conditions. On the expiratory limb, listening is different from tidal breathing, but not as different as independent activity. The child's non- time and volume normalized waveforms show no discernible differences between the listening condition and tidal breathing in terms of slope (the waveforms do differ in timing, however timing is analyzed in *Analysis B* in greater detail). The independent activity condition however, is different in slope on the inspiratory limb. This observation can be made on the expiratory limb in the time and volume normalized waveforms. Again, no apparent difference exists between the listening condition and rest breathing in these waveforms either. However, a difference can be observed between the independent activity and rest breathing, particularly on the expiratory limb.

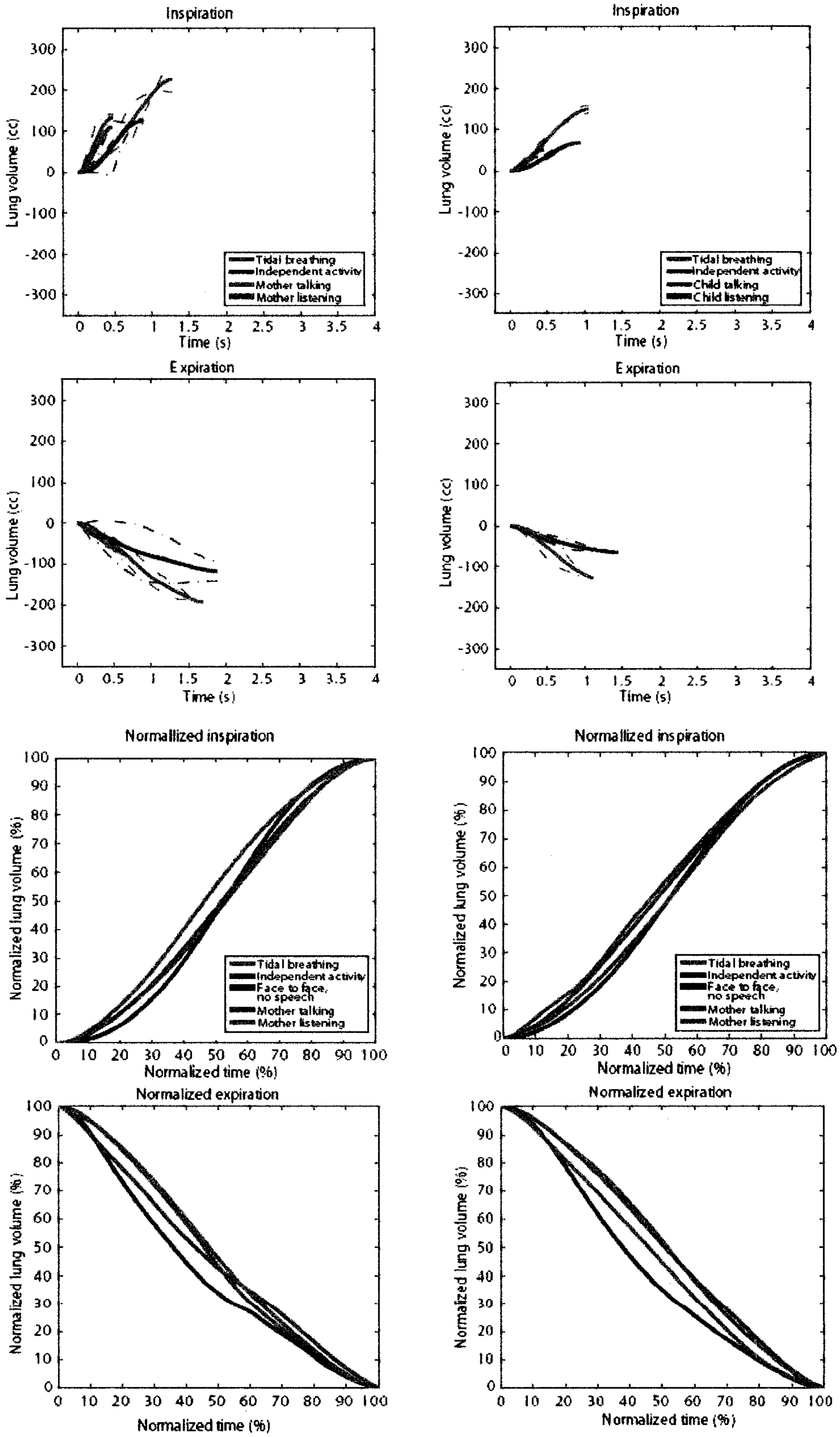


Figure 12a. Non-and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

### *Dyad #6: Child with ASD*

The mother rated herself as not very talkative, open or sociable in the Parent Questionnaire. The child was 4 years old and 11 months at the time of the experiment. He was reported to have started talking approximately 6 months prior to the date of the home visit. His mother mentioned that he did engage in turn-taking, but not so much with speech, that he could attend to the same objects as she did and that he could communicate requests and ask questions using a rise in pitch. See table 2 for a summary of this dyad's details.

During the session, the child was observed to have good eye contact when vocalizing and could put together up to three words (e.g., "Mommy, lady help"). Most of his utterances were two-word combinations such as "key up" and "all done". He was also observed to use some location words (e.g., 'in', 'on') and respond appropriately to requests. The mother was skilled at engaging her child's attention using animated play, different toys of interest and following her child's lead. The child's aide acted as the third person present during the session for background support. Although the fire alarm went off during the session, the child appeared to be at ease throughout the recordings upon returning to the testing session.

### *Condition Time-Segment Description*

Table 13 summarizes the number of selected inspirations and expirations for each condition and subject as well as the respective durations of the segments chosen for each condition.

Table 13. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 15 | 7 | 7 | 13 | 7 | 7 |
| Independent Activity | 92 | 30 | 32 | 92 | 57 | 59 |
| Face-to-face, no speech | NA | | | NA | | |
| Listening | 47 | 1 | 3 | 47 | 9 | 5 |
| Talking | | 8 | 5 | | 8 | 3 |

Below follows a brief description of what happened during each condition.

*Tidal breathing.*

The mother was about to open the magazine and was not looking at her child during her segment. During his time segment, the child observed a box of toys while his mother was turned away.

*Independent activity.*

The mother's and child's segments for this condition were taken from the same time in the session (i.e., happening simultaneously). However, the child vocalized a lot in an attempt to recapture his mother's attention, while the mother appeared to watch the child for about 50% of the time during this condition.

*Face-to-face, no speech.*

Although this condition was intentionally attempted by the mother (she asked the child to look at her, but this segment resembled interaction and was not used) and the researcher also looked for instances of it occurring naturally in the session, no segments were found.

*Conversation.*

The segments chosen for this condition involved the mother and the child playing with play dough and talking about what they were making. The child made eye contact with his mother almost every time he spoke to her. During the second segment, when his mother misunderstood him, he also repeated himself. Table 14 summarizes the nested variables observed during these segments.

Table 14. Communicative Events for the Conversation Segments Chosen:

| | | Segment #1 | Segment #2 |
|---|---|---|---|
| **Communicative Event** | | # Occurrences | # Occurrences |
| Eye contact | | 4 | 3 |
| Non-verbal communication (nods, shakes of head, pointing) | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Non-word vocalizations | | 0 | 0 |
| | Contingent | | |
| | Non-contingent | | |
| Word utterances | | 4 | 7 |
| | Contingent | 4 | 7 |
| | Non-contingent | 0 | 0 |
| Turn-taking events | | 4 | 7 |
| Breath holds | | 0 | 0 |

*Quantitative Results*

*Analysis A.*

Figure 12b summarizes the mean and standard deviation waveforms for this dyad. The non- time and volume normalized waveforms for the mother show a clear difference in slope between the listening condition and rest breathing. On her expiratory limb, the slope of the listening condition is similar to that of the independent activity (again, any differences in timing will be discussed later, in *Analysis B*). The time and volume normalized waveforms for the mother also show a marked difference in the shape of the listening waveform from that of tidal breathing. This difference is more apparent on the inspiratory limb. The child's non- time and volume normalized waveforms show no differences between the conditions in inspiration; during expiration, a difference in the listening waveform from that of rest breathing can be seen. His time and volume normalized waveforms show a significant difference between the listening condition and rest breathing, in both the inspiratory and expiratory limbs. Caution should be exercised when interpreting these results, as the number of breaths available for the listening and talking conditions were low.

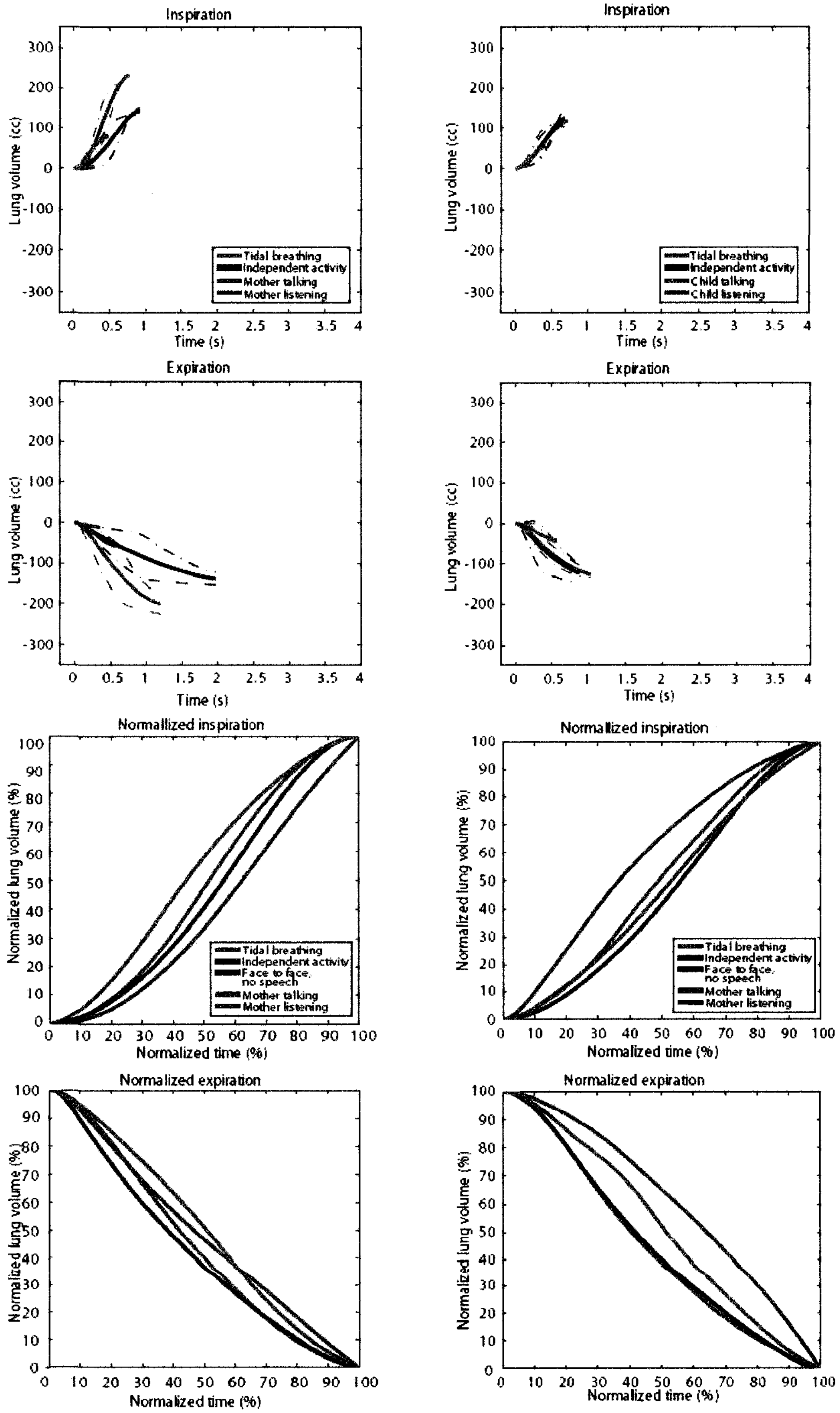


Figure 12b. Non-time and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

The composite waveforms for this group can be seen in figures 12c and 12d. One observation that can be made from these waveforms is that the independent activity waveform for both mothers and the child in the control dyad exhibit longer expiration durations and a decrease in volume. In the control dyad, the mother and her child decrease their volumes and durations of their cycles in the listening condition. In the experimental dyad, a similar observation can be made. In this latter dyad, a remarkable similarity can be noted between the expiration shape of the mother's listening condition and that of the child's talking condition.

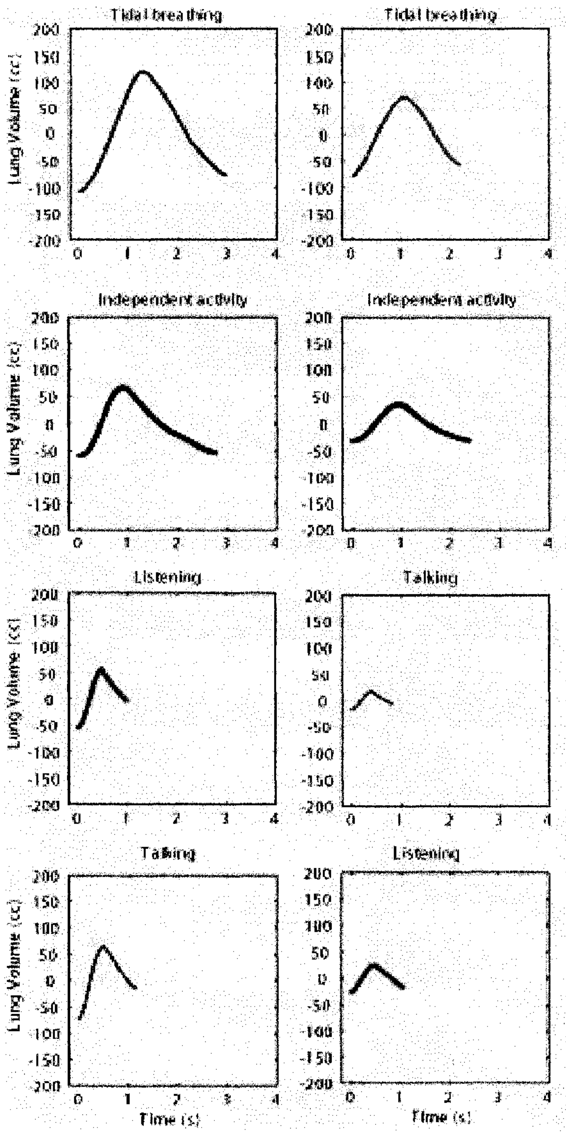


Figure 12c. Composite waveforms for the control dyad in this group (mother, child), for all conditions.

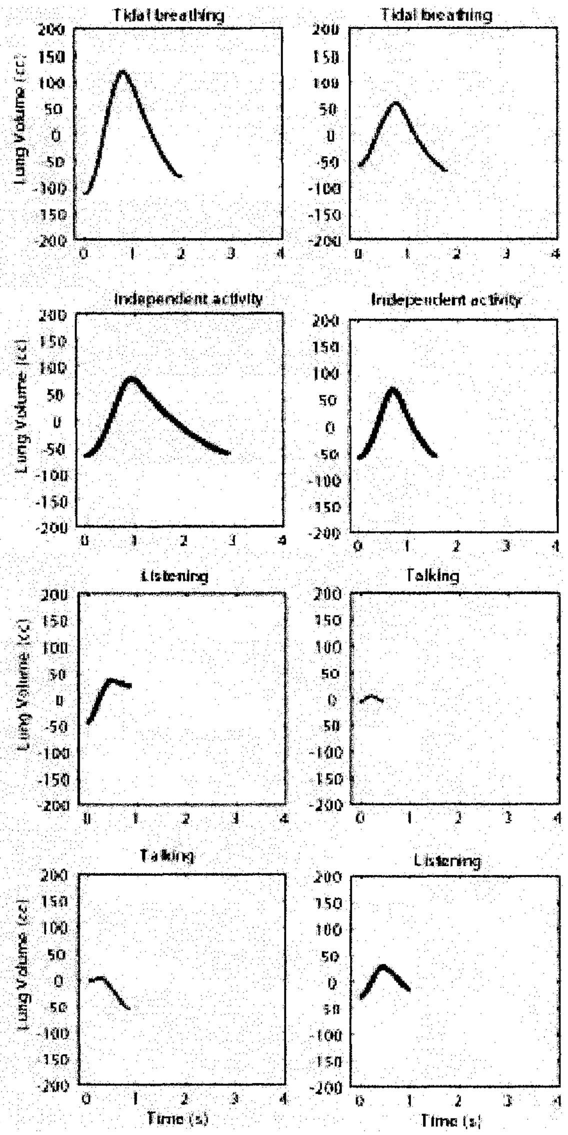


Figure 12d. Composite waveforms for the experimental dyad in this group (mother, child), for all conditions.

### Face-to-Face, No Speech Condition

As mentioned earlier, this condition was analyzed separately from the others because reliable instances of this condition could only be collected for two dyads. Only composite graphs were done for this condition, depicted in Figure 13. The cycle duration for all subjects below appear to be the same as those of their respective tidal breathing cycle durations; the cycles are not distinctly shorter in duration as observed in the listening and talking conditions. However, at least in the case of the two mothers, there is a difference from rest breathing in the volume of air exchanged; the two mothers breathe in less air during this condition. The waveforms of the control dyad in group 1 also appear to mimic speech breathing: shorter inspirations and longer expirations when compared to rest breathing. The mother and child in this dyad were ‘making faces’ to one another during this condition which may be responsible for the observed pattern. Another possible explanation is that perhaps some level of perturbation in the breathing patterns can occur from simply having eye contact with a communication partner or being in a face-to-face position. This trend was also observed in some of the independent activity waveforms (Fig. 11c, 11d, 12c, 12d). Mehrabian (1968a; 1968b) writes that an estimated 93% of what we communicate in interpersonal interactions is through nonverbal means, through paralinguistics (e.g., pitch, volume) or proxemics.

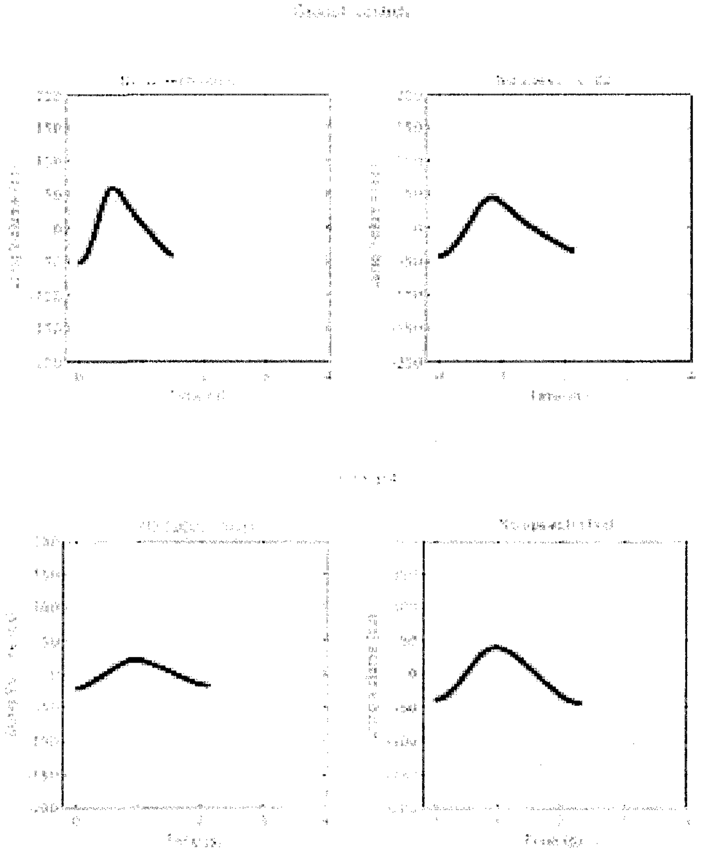


Figure 13. Composite graphs for the face-to-face, no speech condition, for dyads #1 and #5.

*Analysis B*

The following figures display the mean durations for the inspiratory and expiratory limbs. Figures 14a and 14b show these values for all the control dyads. While the subjects were talking, the inspiratory limb appeared to shorten in duration from tidal breathing. This is characteristic of speech breathing and has been previously observed by McFarland (2001) and Boliek et al. (2006a; 2006b; 2003). Interestingly, the same observation can be made while the subjects were listening. On the contrary, inspirations during the independent activity appear to be similar in length to or longer than those acquired during tidal breathing. A similar trend is observed on the expiratory limb: the listening and talking conditions both produced expiratory durations shorter than the tidal breathing expiratory durations; the independent activity condition produced expirations longer than those observed in tidal breathing.

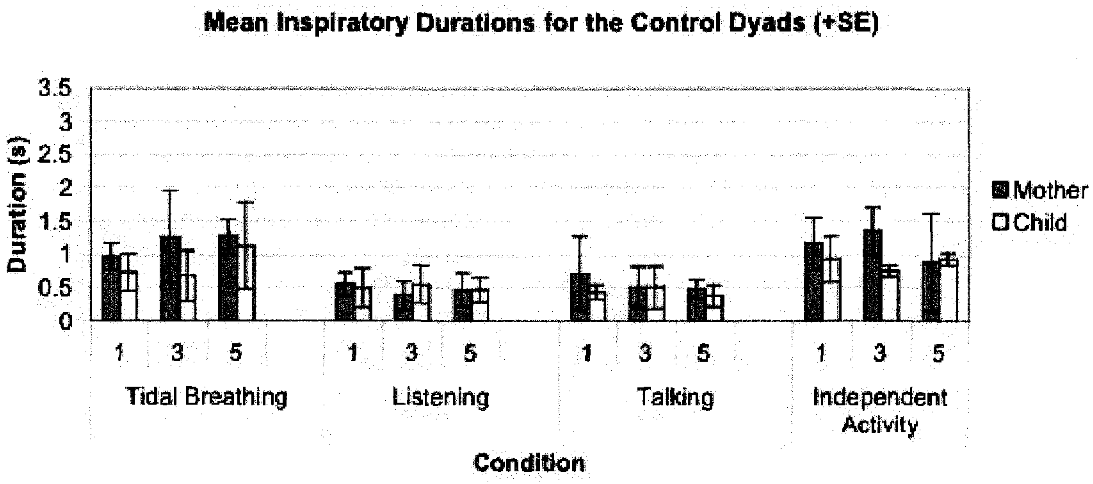


Figure 14a. Mean inspiratory durations and standard deviations for the control dyads (s). Each control dyad is numbered respectively (#1, #3, #5).

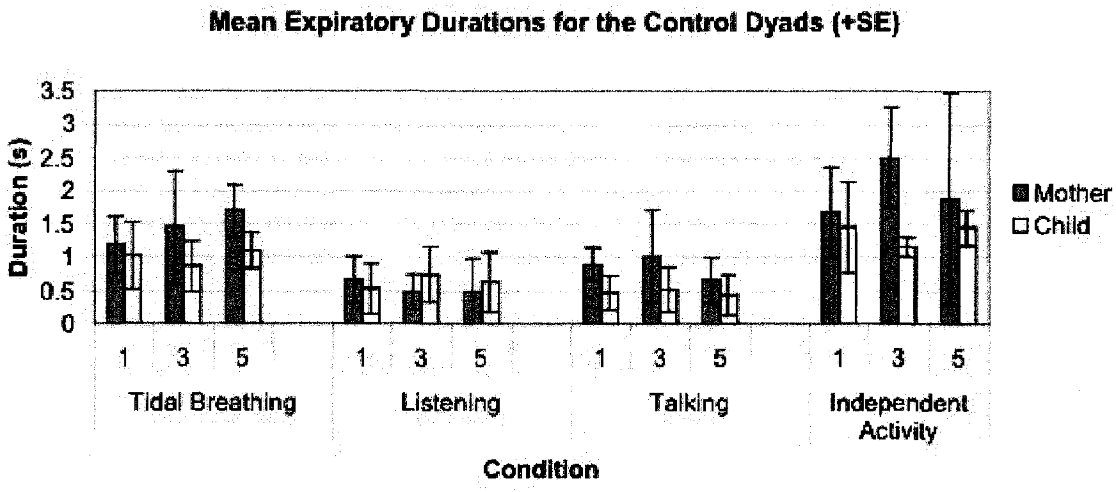


Figure 14b. Mean expiratory durations and standard deviations for the control dyads (s). Each control dyad is numbered respectively (#1, #3, #5).

The following figures (Fig. 15a, b) depict the mean inspiratory and expiratory durations for the experimental dyads. Although less evident, the trends appear similar to the ones observed in the control dyads. When the subjects were talking and listening their inspiratory and expiratory durations shortened from tidal breathing. Longer inspiratory and expiratory durations during the independent activity when compared to tidal breathing were also observed. This trend is most apparent for the sixth dyad. The child in this dyad appeared to be the highest functioning out of the three children with ASD in this study. He was also the only one who was able to produce word utterances and combine words. He was also the oldest child with ASD in the study.

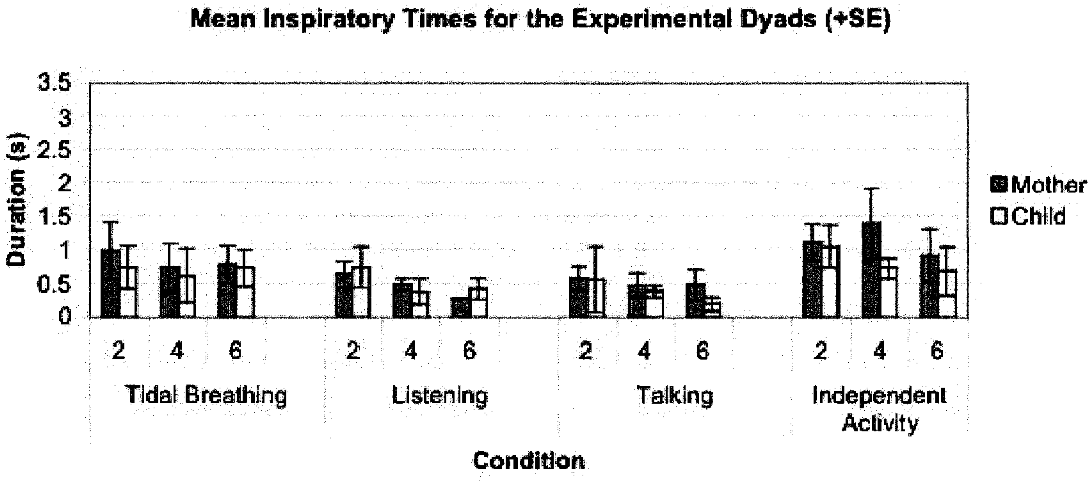


Figure 15a. Mean inspiratory durations and standard deviations for the experimental dyads (s). Each experimental dyad is numbered respectively (#2, #4, #6).

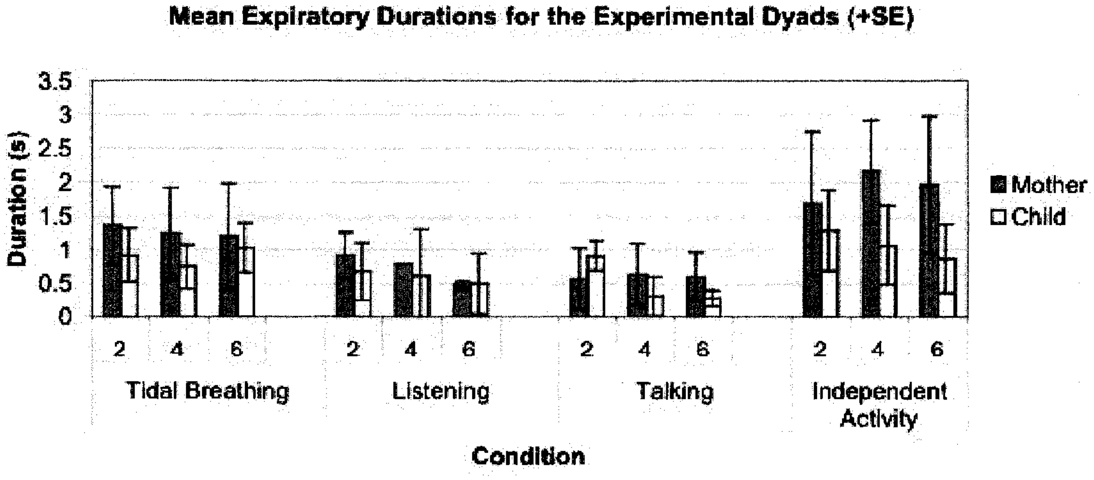


Figure 15b. Mean expiratory durations and standard deviations for the experimental dyads (s). Each experimental dyad is numbered respectively (#2, #4, #6).

Statistical differences and non overlapping standard deviations to identify differences were difficult to employ because the number of breath groups obtained was relatively low and the duration variation was high. To determine the presence or absence of any trends in a more reliable manner than a visual one, the researchers looked for differences in the mean durations between the conditions (see Appendix D for full results). When mean durations in the listening condition were compared to mean durations in the tidal breathing condition, a difference of 0.5 seconds or greater was considered worth noting. A time difference of 0.5 seconds was a conservative number chosen based on the findings of a large developmental study (n=60) (Boliek, Hixon, Watson, & Jones, 2007). Boliek et al. have found a standard deviation of .12 seconds in the inspiration duration and .38 seconds in the expiration duration, in the speech breathing of children 4 years of age (2007).

Using the above criterion, the following results were obtained. For details of the results of these analyses, see *Appendix D.*

Group 1: For the control dyad in group 1, both the mother and the child showed a decrease in duration in the expiratory limb of the listening condition from rest breathing. For the experimental dyad in that group, a decrease in duration in the expiratory limb of the listening condition from rest breathing was observed for the mother; no difference was observed for the child in either the inspiratory or the expiratory limb during the listening condition.

Group 2: The control dyad in group 2 had the mother show a decrease in duration in both the inspiratory and expiratory limbs of the listening condition from rest breathing. Her child did not show a difference however between these two conditions.

This can be attributed to the nature of the segment used for the tidal breathing condition for this particular child; both parents were talking in the background. As mentioned in *Analysis A*, it is possible that the child was attending to them, making this segment better suited for the 'listening' condition. If that is indeed the case, it makes sense that one would not see a difference between these two conditions. In the experimental dyad, the mother shows a decrease in duration in the expiratory limb of her listening condition, from rest breathing, while the child does not show any change.

Group 3: The control dyad in this group had both the mother and the child show a decrease in duration in the inspiratory and expiratory limbs in the listening condition, from rest breathing. The mother in the experimental dyad showed the same pattern, whereas her son displayed a decrease in duration in the listening condition only in the expiratory limb, from rest breathing.

*Presence of entrainment*

The presence of entrainment, or a perturbation in the breathing patterns of the listener from rest breathing, was not only analyzed in terms of cycle durations (*Analysis B*), but also in terms of volume exchanged and volume exchanged per unit of time (i.e., flow) (*Analysis A*). Table 15 summarizes the findings from all analyses above. The conclusions drawn from the non- time and volume normalized waveforms are included within the context of the composite waveforms which were derived from the non-time and volume normalized waveforms.

Table 15. Presence of a perturbation in the listening condition, from rest breathing, as concluded from the analyses in this experiment.

| | Time and Volume Normalized Waveforms | | Composite Waveforms | | Duration | |
|---|---|---|---|---|---|---|
| Control Dyads | Mother | Child | Mother | Child | Mother | Child |
| 1 | X | √ | √ | √ | E | E |
| 3 | X | - | √ | - | √ | - |
| 5 | E | X | √ | √ | √ | √ |
| Experimental Dyads | | | | | | |
| 2 | √ | X | √ | X | E | X |
| 4 | E | X | √ | X | E | X |
| 6 | E | √ | √ | √ | √ | E |

X = absence of a perturbation in both the inspiratory and expiratory limbs; √ = presence of a perturbation in both the inspiratory and expiratory limbs; E = presence of a perturbation in the expiratory limb only.

## DISCUSSION

This study attempted to enhance our understanding of communicative entrainment during face-to-face interactions with young children diagnosed with ASD and a matched group of young, typically developing children. Entrainment in breathing patterns, for the purposes of this study, was defined as a significant perturbation in the breathing waveforms during conversation relative to those from rest. The presence of this phenomenon was identified through a series of analyses of mean inspiratory and expiratory waveform shapes as well as mean inspiratory and expiratory durations from signals generated by each dyad member.

The general prediction was that young children who have a diagnosis of ASD would not produce respiratory patterns indicative of communicative entrainment during face-to-face interactions with their mothers. It was hypothesized that: (1) in typically developing children, inspiration and expiration patterns would differ depending on whether they were at rest or listening to their mother; and (2) in children who have a diagnosis of ASD, the inspiration and expiration patterns would be the same regardless of whether they were at rest or listening to their mother.

Perturbations observed in all variables analyzed in this study were summarized in Table 15 of the *Results*. In the control dyads, mothers and children exhibited a perturbation in their breathing from rest in 2 or more of the 3 methods of analysis summarized. As mentioned above, the child in dyad #3 appeared to not exhibit any perturbation from 'tidal breathing' in the listening condition because her parents were conversing during her 'tidal breathing' segment. As a result, this child may have been entraining to one or both of her parents, although overtly she appeared to not be engaged by the background conversation. In the experimental dyads, all mothers exhibited perturbations from tidal breathing in all 3 methods of analysis summarized (Table 15). Two children with ASD showed no remarkable perturbation from rest breathing during their listening condition in all methods of analysis. However, of interest was the child with ASD in dyad 6 who displayed a presence of entrainment in all 3 methods of analysis summarized. This is remarkable because this child was the only one in this experiment who could systematically engage in a conversation with his mother and could formulate 2 to 3 word sentences. He was also the oldest child with ASD in this study. It should also be noted that although no significant perturbations from rest breathing when listening were observed in the other 2 children with ASD, they did display this phenomenon in a milder form. There was also a limited selection of segments for the conversation condition for these latter two children. If the interactions had been longer, perhaps a perturbation would have been more evident. From the above results, a gradation of entrainment is speculated by the author, one that is correlated with either the level of functioning of the child with ASD or their age and experience with social interactions or some combination of both. Another interesting observation that can be made from the experimental dyads is that entrainment is not reciprocal between the two dyad members; mothers in these dyads entrained to their children even when these children did not entrain to their mothers.

Occasionally, perturbations in breathing patterns were observed when the subject's attention was engaged by a magazine or a toy. These changes however, were distinctly different from the breathing patterns observed during the listening conditions; an increase in cycle duration rather than a decrease was always the case. In addition, these perturbations did not mirror the patterns observed in the speech breathing of the communication partners. These results support McFarland's conclusions (2001) that entrainment during listening is not simply an artifact of increased arousal. Some perturbations from rest breathing were also observed in the face-to-face, no speech condition as well. This observation could mean that entrainment may occur even when the communication partners are simply facing one another. O'Conaill et al., (1993) and Sellen (1995) found that when providing only audio, or audio and video signals, of the communication partner, the conversational exchange became less natural. The results of this study support McFarland's conclusion that signals exchanged in face-to-face interactions specifically, "are importantly involved in the precise coordination necessary for normal conversational turn taking" (2001, p.141).

As mentioned above, the present results revealed a perturbation from quiet breathing of typically developing children and their mothers during face-to-face communications. The observed perturbation appeared to mirror the speech breathing of their conversational partner. However, the strength of this coupling varied between the control dyads. This is concordant with previous findings (McFarland, 2001; Warner, 1996; Warner et al., 1987). It was also hypothesized that this perturbation would be characterized by shorter and faster inspirations and longer and slower expirations (similar to speech breathing). However, the pattern observed in this study was that of a shortening of both the inspiratory and expiratory limbs, as well as a decrease in the volume of air exchanged. This could be explained by the difference in utterances between adults and young children. Adults tend to converse in longer utterances which would explain the pattern observed by McFarland (2001): shorter inspirations and longer expirations. The mothers in this study however made utterances shorter in length because they were modifying their speech based on the younger listener. It can be concluded then that during entrainment, the breathing of the listener mirror those of the speaker regardless of what these may look like.

McFarland found it interesting that the differences he observed occurred primarily in the inspiratory duration, since speech is produced during the expiratory phase (2001). He concluded that the changes in the inspiratory duration most consistently differentiated speech from quiet breathing, while the expiratory duration was more sensitive to utterance complexity. He speculated that inspiratory duration may be more sensitive to a shift from quiet breathing to speech function. No subjects in the present study have shown entrainment on just the inspiratory limb; perturbations were observed either in both the inspiratory and expiratory limbs, or in just the expiratory limbs. This finding is concordant with those of Boliek et al., (2006a; 2006b): the expiratory limb is the more common of the two to reflect a perturbation.

The results of the present study show that entrainment is not entirely absent in children with ASD, as was initially hypothesized. From this study, it can be concluded that this phenomenon is present, but altered. Since even lower functioning animals exhibit some type of entrainment, this rhythm generation may be under automatic neurological control at the subcortical level. However, an abstract processing of suprasegmentals, most importantly timing, also appears to be essential and since children with ASD are not picking up on the conversational rhythmicity and other suprasegmental aspects of speech, they may not incorporate all the cues from their partner when exhibiting entrainment resulting in a weakened or altered entrainment pattern. This could be a physiological manifestation of the atypical neurodevelopment characteristics of ASD observed by Courchesne et al. (2003). In other words, due to the underconnectivity observed in the ASD brain it can be reasoned that low-level, basic information processing may be relatively spared, but it may fail to be used in the serve of high-order context-based behaviour. Contrary to our beliefs, even if children with ASD are not picking up on the conversational rhythmicity and other suprasegmental aspects of speech, they may still entrain to the speaker to some extent, but possibly at a lower, physiological level.

The most exciting finding of this study was that entrainment was confidently observed in a child previously diagnosed with ASD. It was surprising to see a perturbation special to communicative acts in these children even if this perturbation was only a slight trend in two of the three and a strong trend in the highest-functioning child. The question posed at the beginning of this study remains: can entrainment serve as a maker for identifying ASD early on? The results of this study would conclude that this is not the case. Subsequent studies, looking at a more stringent definition and inclusion criteria for level of functioning and how that level correlates with entrainment, outside of age variables, are of significance. What serves as an important conclusion from the findings of this particular study is that the lower order patterns of respiratory entrainment specific to speech are not translated into observable suprasegmental behaviours (e.g., comprehension of pitch, intensity and durational differences in the speech of their mother).

The results in this study have a direct clinical application. Even if entrainment is not a clear marker of ASD, this phenomenon is still valuable in intervention. There may be a way to enhance respiratory rhythmicity very early on when the process of local overconnectivity issues are at their height. Research looking at a longitudinal approach to determine whether entrainment can be a learned behaviour in children with ASD may be able to answer this question.

A second important finding of this explorative research was that this procedure, initially carried out with typically developing infants and adults only, can be applied to some children diagnosed with ASD. All children in this study were at ease during the experiment, as reported by their mothers and observed by investigators. None of the children had difficulties wearing the Respitrace bands or with remaining in the same spot for twenty to thirty minutes. The help provided by the mothers and aides who participated in this experiment was vital to its success.

Another finding was that of variation among measurement variables used to determine the presence or absence of entrainment. It became apparent early in the data analysis that a clear definition of entrainment and associated rules for data interpretation was needed. Specifically, the data from the current study examined differences in volume of air exchanged, in the flow of air and in duration. Should entrainment be defined as a perturbation in all of these variables, or is perturbation in just one variable enough to recognize the pattern as entrainment? Similarly, when looking at inspiration and expiration individually, should a perturbation in both of these limbs be apparent, or is one enough? McFarland (2001) looked at entrainment as a perturbation from rest breathing in the inspiratory and expiratory durations and at a temporal correspondence between the respiratory waveforms. Boliek et al. (2006a; 2006b) looked at the shapes of inspiratory and expiratory non- time and volume normalized and time and volume waveforms, durations, running correlations and a number of other variables. It is reasonable to assume that when the results from various analyses converge, it can be interpreted as strong evidence for the presence of entrainment.

## LIMITATIONS OF THIS STUDY

One limitation of this study is that the observers of the interactions were not blind to the diagnosis, nor was the interpretation of the results. A second limitation is that in the set-up of the interaction, the mother and her child should have been seated at the same eye level. As with any interaction between adults and children, the children are most engaged when the adult is situated down at their level. This could be accomplished in the future by having the mother sit on a lower chair. Another limitation of the study is the relatively small number of participants and their variability in language development and behaviour. A greater number of participants would increase the strength of these findings and the likelihood that children willing to do the conditions are found. In future studies, the children should also be matched on verbal intelligence. Finally, this study will need to be replicated to ensure that these observations are robust and that this procedure is reliable.

## FUTURE RESEARCH

Some further analysis could be made on the data already obtained in this experiment. Boliek et al. (2006a; 2006b) have applied other means of analysis to their data to determine the presence and further understand the nature of entrainment. These means include a running correlation between the two subjects in the dyad as well as other phase relation measures of respiratory behaviour during baseline and experimental conditions. These latter measures are: (a) lung volume initiation, termination, and excursion (in cc); (b) lung volume initiation, termination, and excursion (in percentage predicted vital capacity, %PVC); (c) rib cage volume initiation, termination, and excursion (in cc); (d) abdomen volume initiation, termination, and excursion (in cc); (e) rib cage relative volume contribution to lung volume excursion (in % rib cage); (f) syllable rate in syllables per second; (g) syllables per breath group; (h) lung volume excursion per syllable (in cc/syllable); and (i) lung volume excursion per syllable (in percent predicted vital capacity per syllable).

There are numerous research opportunities in this area as entrainment of breathing in face-to-face conversations is a very new and under researched topic. A closer look at this phenomenon in the typical population is needed to better understand the nature of entrainment. For example, in a conversation, how long does it take for entrainment to occur, what causes it to become interrupted and how does this vary with the age of the participant? It would also be of interest to correlate the strength of entrainment with the level of language development.

This study also raises numerous questions about entrainment of breathing patterns in people with ASD. Does it take this population longer to entrain to their communication partners, and is there a relationship among language development, length of communication engagement, other social behaviours and setting? What do the breathing patterns of adults with ASD look like when they are communicating with familiar persons? Can entrainment be learned through increased social practice and intervention? In addition, employing a longitudinal study on sibling infants of children with ASD may be useful in determining if the respiratory marker is present or not at birth and evaluate its use in predicting the developmental disorder. Finally, entrainment in this population and other atypical populations should be studied with unfamiliar communication partners to determine if there is a change in the breathing patterns and/or if entrainment takes even longer to establish.

## DEFINITION of TERMS

**BOLD fMRI** — blood-oxygenation level dependent functional magnetic resonance imaging: functional magnetic resonance imaging that relies on intrinsic changes in hemoglobin oxygenation (wordnet.princeton.edu/perl/webwn).

**Conversation** — a time when both communication partners are attending to one another or to the same objects; occasional utterances may occur in a sequence of turn-taking events and the two partners may have occasional eye contact.

**Entrainment** — (for the purposes of this study) defined as a significant perturbation in the breathing waveforms from baseline, or tidal breathing waveforms, that is characterized by shorter and faster inspirations and longer and slower expirations (similar to speech breathing). For this study, entrainment will not include phase-locked respiratory signals between participants.

**High- to moderate- functioning ASD**— This aspect was not determined by any standardized measures. Rather, it was determined behaviourally by the types of speech produced by the child (e.g., intelligible words, non-recognizable sounds, etc.), the complexity of the child's play (e.g., playing with only one object, playing with a variety of toys appropriately, etc.), along with other indices of function such as joint-attention, ability to follow directions and answer questions.

**Interaction** — See *conversation.* In this paper, the two terms will be used to refer to the same type of communication.

**Motherese** — the modification adults make in their speech when talking to young children.

**Prosody** — term used to refer to speech elements such as intonation, pitch, rate, loudness, rhythm, etc. www.csa.com/discoveryguides/linglaw/gloss.php.

**Synchrony** — See *entrainment.* In this paper, the two terms will be used to refer to the same phenomenon.

**Tidal breathing** — Breathing at rest, or baseline breathing.

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## APPENDIX A — Parent Questionnaire

### PHYSIOLOGICAL AND BEHAVIORAL PATTERNS DURING AN INFANT-MOTHER FACE-TO-FACE INTERACTION

Please place a vertical line through the horizontal one for each of the 20 questions below to estimate how you would describe yourself for each of the characteristics listed.

1.
Talkative ------------------------------------------------------------------------------ Silent

2.
Frank ,open ----------------------------------------------------------------------------Secretive

3.
Adventurous ----------------------------------------------------------------------------Cautious

4.
Sociable ----------------------------------------------------------------------------Reclusive

5.
Good-natured ----------------------------------------------------------------------------Irritable

6.
Not Jealous ------------------------------------------------------------------------------ Jealous

7.
Mild, Gentle ------------------------------------------------------------------------Headstrong

8.
Cooperative ----------------------------------------------------------------------Negativistic

9.
Fussy, Tidy ----------------------------------------------------------------------------Careless

10.
Responsible ----------------------------------------------------------------------Undependable

11.
Scrupulous ----------------------------------------------------------------------Unscrupulous

12.
Persevering ----------------------------------------------------------------------------Quitting,
Fickle

13.
Poised ----------------------------------------------------------------------------Nervous,
Tense

14.
Calm ----------------------------------------------------------------------------Anxious

15.
Composed ---------------------------------------------------------------------------- Excitable

16.
Not ------------------------------------------------------------------------------ Hypo-
Hypochondriacal chondriacal

17.
Artistically -------------------------------------------------------------------------Artistically
Sensitive Insensitive

18.
Intellectual ----------------------------------------------------------------------Unreflective

19.
Polished, Refined ------------------------------------------------------------------------------ Crude, Boorish

20.
Imaginative ------------------------------------------------------------------------------ Simple, Direct

Adapted from Norman, W.T. (1963) Toward an adequate taxonomy of personality attributes: Replicated factor structure in peer nomination personality ratings. Journal of Abnormal and Social Psychology, 66, 547-583.

## APPENDIX B — Questionnaire ASD1

1. What does your child prefer to look at? What types of situations does he/she seem to focus on, pay attention to, participate in?
2. How would you describe your child's attention? Do you think your child would be okay during this experiment? Can your child sit down and attend to books, games, toys, etc.? For how long?
3. How fast does your child habituate or become used to a new environment? If your child had to wear these bands around his/her chest and tummy, do you think he/she could handle it?
4. Describe how your child communicates with you?
5. Does your child use gestures?
6. Does your child take turns during interactions?
7. Can your child attend to the same objects you do?
8. How long can you typically engage him/her in an interaction?
9. How does your child let you know when he/she is upset or uncomfortable?
10. How does your child let you know when he/she is happy and content?
11. What could we do in advance to make the session a better experience for you and your child?
12. Could you bring some toys/ books that will engage your child in an interaction with you?
13. Is there a time of the day when your child engages best?
14. What are some other concerns you have about this experiment?
15. Is there anything else we should know about your child that might help him/her be more comfortable? What other things should we have available?

## APPENDIX C — Calibration Procedures

Humans differ in their breathing patterns (fast/slow; deep/shallow) and the relative contribution of the chest wall and abdomen. It was therefore necessary that calibration took these factors into account. Both the child and the mother were fitted with Respitrace bands during the calibration procedures as well as during the experiment itself. First, the volume of air was calibrated against a piston syringe. The volume calibration of the Respitrace bands was then obtained by using a face-mask and a pneumotachometer to measure the integrated flow of air from the mouth and nose of the participant.

The chest wall movements were calibrated using isovolume manoeuvres. This technique involved the participant inhaling some air and holding his/her breath and alternatively contracting and relaxing his/her abdominal wall. As the glottis is closed during this manoeuvre, the net volume is zero because there is no air entering or escaping the lungs. Any resulting contraction of the abdomen therefore will cause an equivalent expansion of the ribcage. In this closed system, the abdomen has to move two to three times more than the ribcage to displace the same amount of volume. Through this calibration, this ratio of relative displacement is accounted for in our signals. Accomplishing isovolumes in the case of the child involved having the child drink and capturing the swallow (breath holding naturally occurs during a swallow) and associate isovolume manoeuvres. All this was done while the child was in the upright-seated position. When recording isovolumes for the mother, she was asked to hold her breath at the end of a sigh and pull her stomach in and ‘let it flop out’. This calibration was also carried out with the mother in an upright-seated position.

The signals from the above calibration techniques were then used to obtain calibration numbers for the signals for all subjects. Below is a brief description of how this was accomplished. These procedures for calibration have been previously used by Boliek et al. (1996; 1997; 2003; 2006a; 2006b) and were shown to be reliable and valid.

First, the segments in the session where the piston syringes were used to introduce a known volume of air to a pneumotachometer and pressure transducer which was then amplified and digitized. A syringe of 100cc and one of 3000cc were used as reference volumes for the child and mother, respectively. The volume signals from this calibration step were used to establish a computer scale for how much displacement there was for a certain volume of air (Fig. 16).

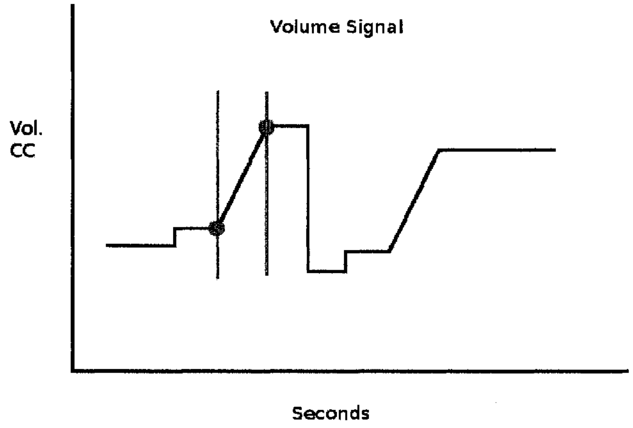

Figure 16. Displacement resulting from a known volume of air inserted into the pressure transducer.

Second, the segment in the session where the child and the mother recorded their respective isovolumes was digitized. An isovolume was selected between the cursors (a place where the lung volume signal was flat, and the ribcage and abdomen signals were equal and opposite, as shown in Fig. 17) and displayed on an XY scale

(X=abdomen displacement, Y=ribcage displacement) (Fig. 18). The slope of this displacement was made to equal –1 (i.e., equal and opposite displacement from the ribcage and abdomen).

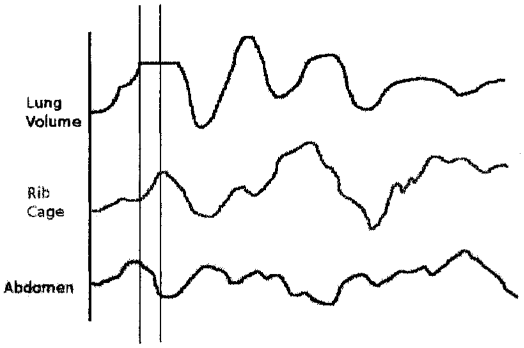

Figure 17. Isovolume represented by abdomen, ribcage and lung volume signals.

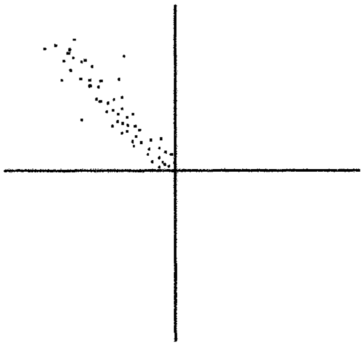

Figure 18. Isovolume displayed on an XY scale.

Lastly, the segment in the session where the child and/or the mother breathed into a face-mask coupled to a pneumotachometer and pressure transducer, integrated and digitized served as a comparative volume to the time-locked kinematic signal. A breath where the lung volume signal derived from the Respitrace was equal in slope to the signal from the airway opening was selected and displayed on the y-time scale again (Fig. 19). This calibration was done so that we can attribute a known volume of air at the airway opening to a known amount of displacement of the summed ribcage and abdomen signals.

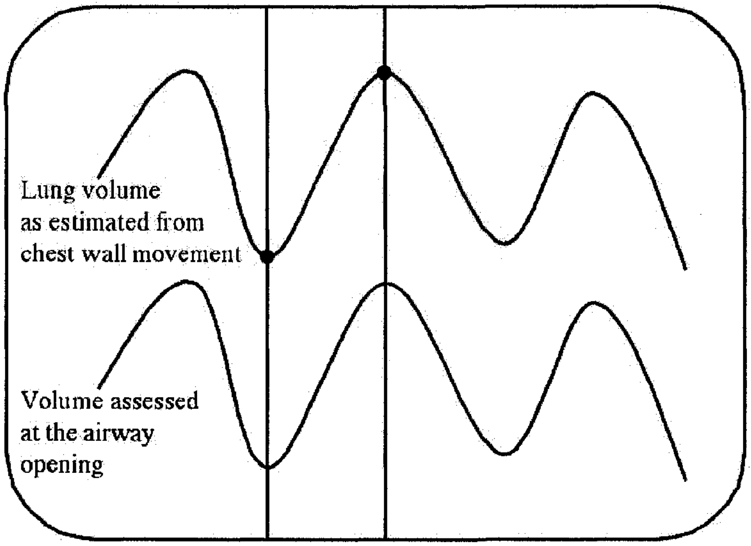

Figure 19. Selected breath for lung volume calibration.

After the calibrations were completed, a section of rest breathing was digitized and lung volume values were derived. These values were checked against predicted volumes obtained from norms based on height and weight.

## APPENDIX D — Calculations for Analysis B

The following tables compare the *mean* times of all conditions relative to that of the tidal breathing task.

Group 1—Control Dyad

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | — | ↓ | — | — | Child (I) | — | — | — | — |
| Mother (E) | ↑ | — | ↓ | — | Child (E) | — | — | ↓ | ↓ |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

Group 1—ASD Dyad

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | — | NA | — | — | Child (I) | — | NA | — | — |
| Mother (E) | — | NA | ↓ | ↓ | Child (E) | — | NA | — | — |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

Group 2—Control Dyad

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | — | NA | ↓ | ↓ | Child (I) | — | NA | — | — |
| Mother (E) | ↑ | NA | ↓ | — | Child (E) | — | NA | — | — |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

Group 2—ASD Dyad

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | ↑ | NA | — | — | Child (I) | — | NA | — | — |
| Mother (E) | ↑ | NA | ↓ | ↓ | Child (E) | — | NA | — | — |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

Group 3—Control Dyad

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | — | — | ↓ | ↓ | Child (I) | — | — | ↓ | ↓ |
| Mother (E) | — | — | ↓ | ↓ | Child (E) | — | — | ↓ | ↓ |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

Group 3—ASD Dyad

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | — | NA | ↓ | — | Child (I) | — | NA | — | ↓ |
| Mother (E) | ↑ | NA | ↓ | ↓ | Child (E) | — | NA | ↓ | ↓ |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

Group 4—Sibling

| | IA | NS | L | T | | IA | NS | L | T |
|---|---|---|---|---|---|---|---|---|---|
| Mother (I) | — | NA | — | — | Child (I) | — | NA | ↓ | ↓ |
| Mother (E) | — | NA | ↓ | ↓ | Child (E) | — | NA | ↓ | ↓ |

I = inspiratory limb; E = expiratory limb; — = there was no difference; ↓ = the mean decreased; ↑ = the mean increased; IA = Independent activity; NS = No speech; L = Listening; T = Talking.

## APPENDIX E — Extra Dyad

### *Dyad #7: Sibling of Child With ASD*

Because the opportunity arose, the sibling of a child with ASD tested in this experiment was also tested on that day. Zwaigenbaum et al. (2005) used siblings of children with ASD as infants at 'high-risk' of being themselves diagnosed with ASD. There was no matched control for this dyad. The interaction between this child and her mother was very natural; the child took a turn every time either by saying something or by laughing and she made eye contact every time she interacted with her mother. Table 16 summarizes the details of this dyad.

Table 16. General Information.

| **Child** | | **Mother** | |
|---|---|---|---|
| Age at Time of Experiment | 4-9 | Age at Time of Experiment | 27 |
| Weight (kg) | 18.16 | Weight (kg) | 81.72 |
| Height (cm) | 107.32 | Height (cm) | 160.02 |

### *Condition Time-Segment Description*

Table 17 summarizes the number of selected inspirations and expirations for each condition and subject as well as the respective durations of the segments chosen for each condition.

Table 17. Summary of Segment Durations and Total Number of Selected Inspirations and Expirations Within.

| | **Mother** | | | **Child** | | |
|---|---|---|---|---|---|---|
| **Condition** | Length of segment (s) | Number of selected inspirations | Number of expirations | Length of segment (s) | Number of selected inspirations | Number of expirations |
| Tidal Breathing | 25 | 10 | 8 | 8 | 3 | 4 |
| Independent Activity | 35 | 12 | 13 | 35 | 15 | 16 |
| Face-to-face, no speech | NA | | | NA | | |
| Listening | 22 | 4 | 2 | 22 | 5 | 3 |
| Talking | | 6 | 3 | | 4 | 3 |

Below follows a brief description of what happened during each condition.

*Tidal Breathing.*

During her segment for this condition, the child was colouring, but her mother was not facing her and was addressing another person. The mother's segment for this condition was taken while she was watching her daughter colour.

*Independent activity.*

The segments for this condition were taken at the same time in the session for both the child and the mother. The child was colouring while the mother flipped through a magazine.

*Face-to-face, no speech.*

The segments for this condition were also taken at the same time in the interaction for the child and the mother. Although they were not phonating, the mother and her child occasionally communicated through sign. Therefore, this segment was not used in the analysis.

*Conversation.*

During this conversation, the mother and the child talked about the toys on the table. The child appeared to be fully engaged and all her utterances were on topic.

Table 18. Communicative Events for the Conversation Segment Chosen:

| **Communicative Event** | | # Occurrences |
|---|---|---|
| Eye contact | | 7 |
| Non-verbal communication (nods, shakes of head, pointing) | | 1 (laugh) |
| | Contingent | 1 |
| | Non-contingent | 0 |
| Non-word vocalizations | | 0 |
| Word utterances | | 13 |
| | Contingent | 13 |
| | Non-contingent | 0 |
| Turn-taking events | | 7 |
| Breath holds | | 0 |

*Quantitative Results*

*Analysis A.*

Figure 20a shows the non- time and volume normalized and time and volume normalized waveforms for the mother and child in this dyad. The mother's non- time and volume normalized waveforms show no remarkable difference between the conditions. This is true of the inspiratory and expiratory limbs. The time and volume normalized waveforms for the mother show a similar trend in expiration. In inspiration there is a notable difference between the listening condition and rest breathing. This is the only instance in this experiment when a difference is noted only on the inspiratory limb. All waveforms for the child show no discernible difference between the conditions, except in the time and volume normalized expiratory waveforms. The listening waveform is markedly different from the tidal breathing waveform. Interestingly, the listening waveform is very similar in shape to that from the face-to-face, no speech condition; the child and the mother were engaged in sign talk during this condition.

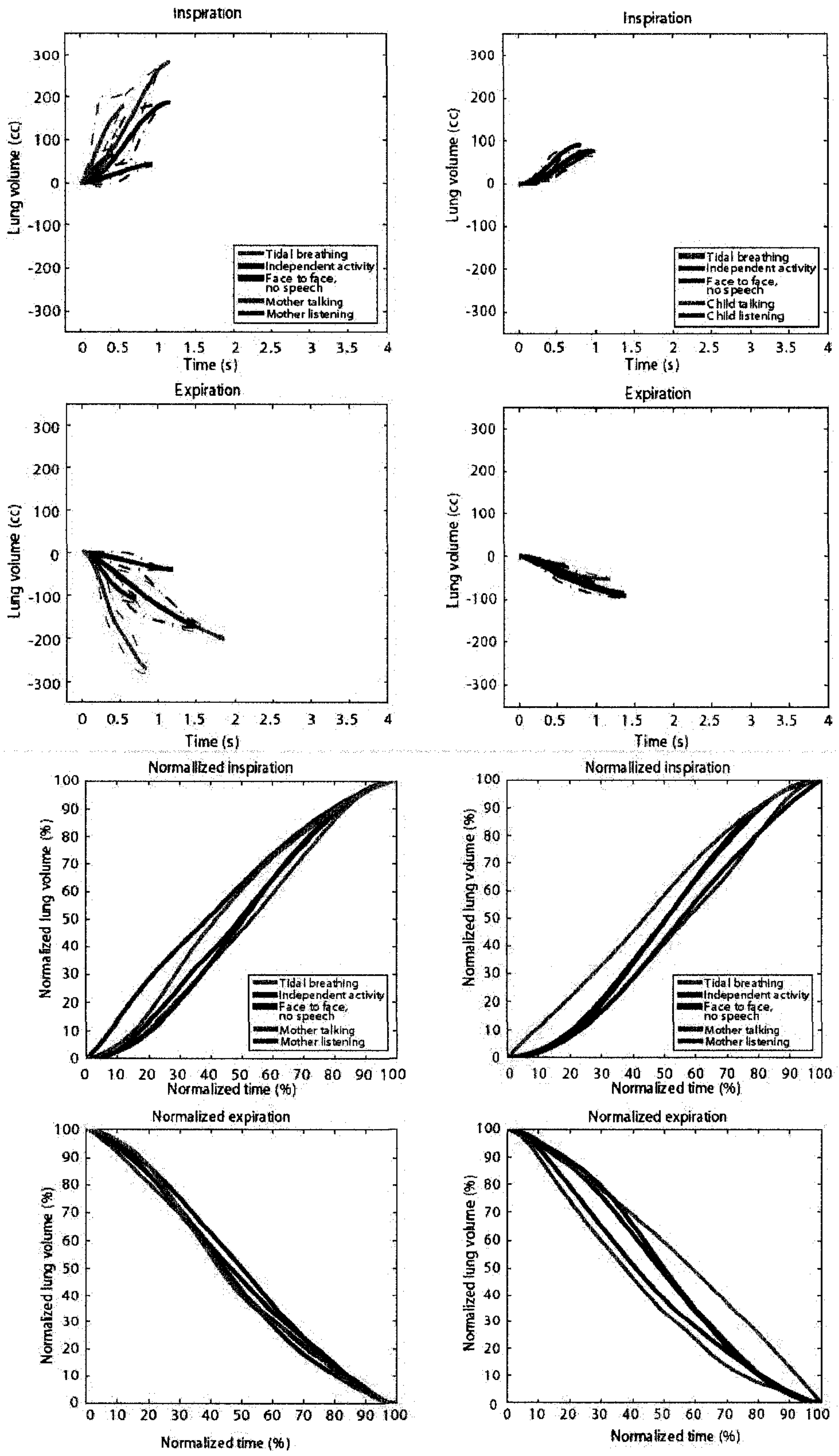

Figure 20a. Non-time and volume normalized and normalized mean waveforms for inspiration and expiration. Each quadrant contains the waveforms for all conditions. The waveforms for the mother are on the left hand side of the figure and the child's on the right hand side.

Figure 20b shows the mean composite waveforms for all conditions for both the mother and child. It appears that the mother shows a decrease in volume of air exchanged during her independent activity condition. This was observed in other subjects as well (e.g., mothers in group 3). Both the mother and the child show a larger decrease in volume, as well as a marked decrease in cycle duration during the listening condition. The mother in this dyad is also the only one in this experiment to show a clear increase in expiration during the listening and talking conditions.

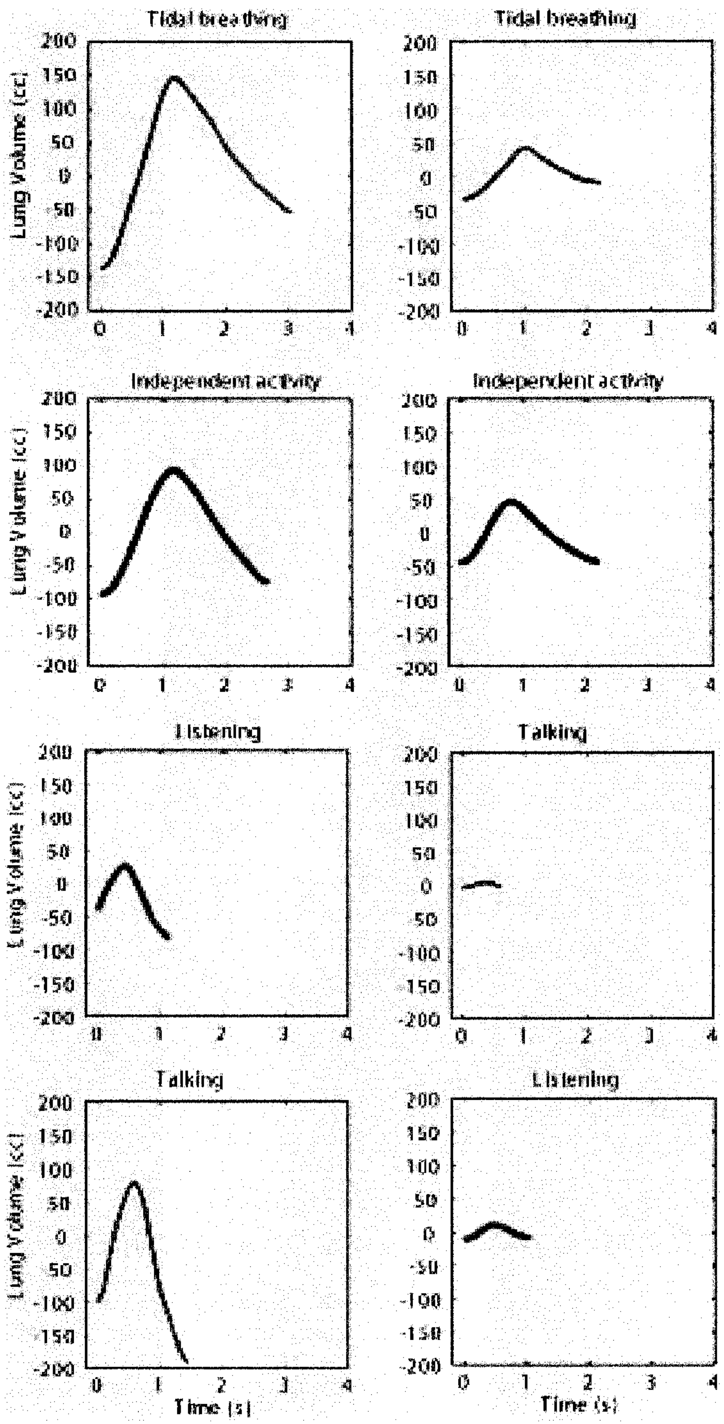

Figure 20b. Composite waveforms for this dyad (mother, child), for all conditions.

*Analysis B.*

As in the case of the control dyads, the inspiratory and expiratory durations appear to shorten from tidal breathing. The breathing durations obtained during the independent activity appear to be equal to or greater than tidal breathing durations.

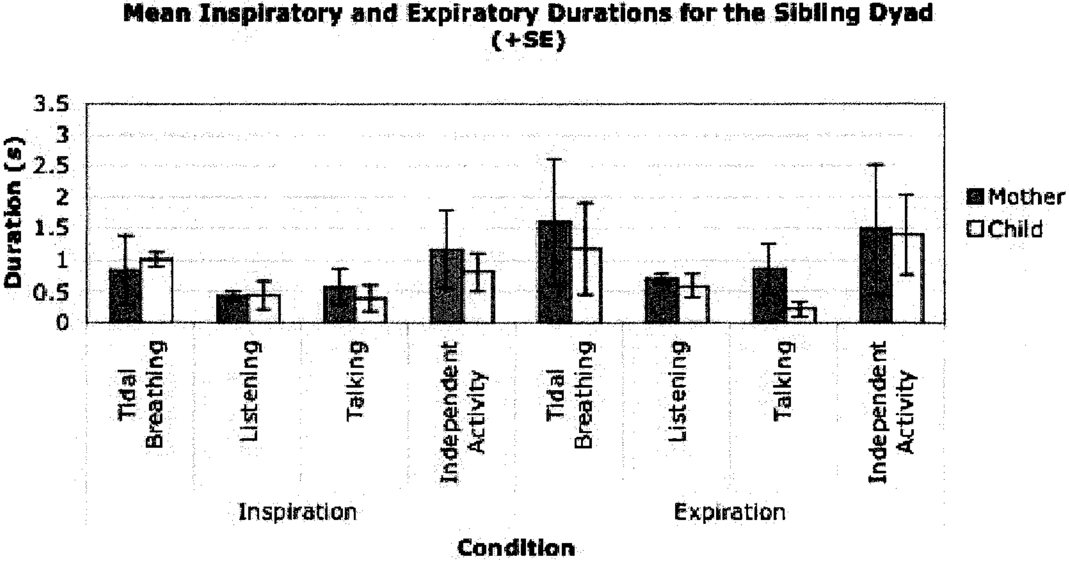

Figure 21. Mean inspiratory and expiratory durations and standard deviations for the sibling dyad (s).

Looking for a difference of 0.5 seconds or greater between the listening task and the tidal breathing task, the mother displayed a decrease on the expiratory limb while the child showed a decrease in both the inspiratory and expiratory limbs. Both the mother and the child in this dyad appear to entrain to one another during their face-to-face interaction.