

ABSTRACT

Title of Document: ASSESSING THE VIABILITY OF STUDYING
MOTION INDICATORS OF AUTISM
SPECTRUM DISORDERS IN INFANTS AT
HIGH AND LOW RISK FOR ASD USING A
PASSIVE MOTION CAPTURE SYSTEM

Eileen Chai, Jillian Chavis, Kevin Chodnicki, Tim
Crisci, Nathan Destler, Duncan Graham, Kesshi
Jordan, Richard Landa, Conrad Merkle, Soh Park,
Christopher Paxton, Rachita Sood, James Tanner,
Brendan Wray

Directed By: Yiannis Aloimonos, Ph.D., Department of
Computer Science, University of Maryland,
College Park

Autism Spectrum Disorders (ASD) are a group of socially debilitating disorders that affect 1 in 110 children. Researchers have long understood that early diagnosis and intervention lead to the best possible outcome for children with ASD, compelling researchers to develop early diagnostic methods. Researchers believe that a better understanding of the effect of ASD on movement will aid in developing these early diagnostic techniques. To assist in understanding the effect of ASD on movement, our team performed a proof of concept study to determine if a passive motion capture system can be used to characterize motion indicators of ASD. To accomplish this goal, our team analyzed three distinct movements in infants, six to twelve months, at high and low risk for ASD. We determined that passive motion capture systems can characterize movement indicators of infants at high and low risk for ASD.

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By

Eileen Chai, Jillian Chavis, Kevin Chodnicki, Tim Crisci, Nathan Destler, Duncan
Graham, Kesshi Jordan, Richard Landa, Conrad Merkle, Soh Park, Christopher
Paxton, Rachita Sood, James Tanner, Brendan Wray

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Advisory Committee:

Professor Yiannis Aloimonos, Ph.D. Chair

Jane Clark, Ph.D.

Leonardo Claudino, MS

John Jeka, Ph.D.

Rebecca Landa, Ph.D., CCC-SLP

Klaus Libertus, Ph.D.

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Eileen Chai
Jillian Chavis
Kevin Chodnicki
Tim Crisci
Nathan Destler
Duncan Graham
Kesshi Jordan
Richard Landa
Conrad Merkle
Soh Park
Christopher Paxton
Rachita Sood
James Tanner
Brendan Wray

2012

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Chapter 1: Introduction

In recent years, motion capture technology has become an invaluable tool with implications in countless fields including animation, crash testing, physical therapy, and facial recognition. Of these, perhaps the most well-known application is the animation field, where artists use motion capture to translate complex human or animal movement into an avatar, to modify or enhance the movement (Kiser, 2009). Scientific motion analysis, however, aims to maintain accuracy and precision in data collection to represent what is genuinely depicted in the movement. Specifically, the collection of vast amounts of data from movement studies can help to establish “normal” movement baselines, which can then be compared to identify abnormal movements and disabilities or evaluate the effectiveness of a therapy. Previous research has used motion capture technology in such diverse applications as monitoring the degeneration of gait in Parkinson’s disease to measuring infant reaching (Madete, Klein, Dunnett, & Holt, 2011; Berthier & Carrico, 2010).

This thesis describes a prospective pilot study that aimed to determine if motion capture technology could be used to study infants at high risk for autism spectrum disorders (ASD). ASD is a neurodevelopmental disorder characterized by qualitative impairments in communication and social interaction. The disorder has also been linked to motor abnormalities. ASD is ideal for study with motion capture technology because of its high societal cost and the potential to use characteristics of motion for earlier diagnosis, which can lead to better social integration.

Our research used the NaturalPoint OptiTrack motion capture system to collect movement data from infant participants aged 6 to 12 months as they performed four distinct tasks relevant to motor deficits linked to ASD. Infant populations present a unique challenge for motion capture systems because of their size, inattentiveness, and inability to follow directions. Although the technology has been used with infants, there is no published, clearly defined methodology on the use of motion capture with infants at risk for ASD. In addition to investigating movement and ASD, our project sought to fill this gap.

1.1 Introduction to Motion Capture Systems

Motion capture is the process of creating a three-dimensional, digital representation of movement. A variety of methods are used to track a set of points through space in order to create these representations, which then allow researchers to model, dissect, and analyze individual movements. Currently, there are a variety of methods that can be used to capture movement data. Three methods – inertial suits, active LED optical systems, and passive LED optical systems – are described below.

Inertial systems rely on form-fitting motion capture suits outfitted with gyroscopes to track movement. The gyroscopes, which are placed at strategic points on the body such as the forearm, back, and head, collect and transmit rotational data to a computer, which then uses a software program to translate the rotational data into a digital model of the movement. The greatest advantage of using an inertial suit is the ability to capture data anywhere within range of the computer's receiver. However, an inertial system is not practical for use on infants because inertial suits

require the capture subject to wear a large battery pack for power. The size and weight of the battery pack would restrict the movement of infant participants, preventing the collection of natural movement data.

Active optical systems rely on capture participants to wear blinking LED lights. Cameras placed around the individual track the movement of the flashing LEDs and forward the tracking data to a computer, which assembles a model of the movement. However, the wired suit could potentially inhibit the movement of participating infants, and the blinking LEDs could distract participating infants from the study's designated movement tasks.

Passive optical systems rely on a series of cameras that emit infrared light. The light emitted by the cameras is reflected by infrared reflective markers that are attached to the person or object being tracked. The light reflected by the markers is then detected by the cameras. When two cameras detect the light reflected off of a single marker, the computer system is able to triangulate the position and track the movement of that individual marker. By tracking the movement of three or more markers, passive optical systems can model the movement of entire limbs. Because of its reflective rather than active markers, the passive system minimizes the size of the motion capture suit worn by the infant. Therefore, the suit's effect on the infant's movement as well as its degree of distraction are decreased.

We chose to use a passive optical system produced by NaturalPoint because of the disadvantages of the suits associated with the active and inertial motion capture systems. In addition, NaturalPoint was an entry-level system that fit our financial

constraints. We aimed to show that such a system could be used for infant motion analysis.

Passive optical motion capture systems have been used to study the movement of both humans and animals as a means to characterize typical movement and aid in the understanding of movement deficits resulting from neurological disorders, such as Parkinson's disease. For example, June Madete and colleagues used a passive optical motion capture system to characterize the gait of hemiparkinsonian rats (Madete et al., 2011). Abnormal gait has been associated with Parkinson's Disease as well as ASD. Additional studies are described in the Literature Review chapter of this paper.

However, as stated before, such systems have not yet been used in the study of infants with ASD. For this population, a motion capture suit needed to be designed and code needed to be written to fit with the NaturalPoint Optitrack system requirements. A custom suit design was needed because the default suit configuration was designed for full-sized adults, not infants. To ensure that the system could consistently maintain line of sight with all of the markers, they had to protrude from the suit. In addition to meeting the system's needs, the suit also needed to meet the needs of the infant participants. Securely fastened reflective markers were required to prevent the infant from forcibly removing markers during the testing session.

The design, creation, and testing of this suit constituted the first portion of our project. The second was to establish the validity and function of this custom designed suit and motion-capture set-up by collecting data on infants with ASD.

Aside from the lack of motion capture studies with infants at risk for ASD, we chose this population for three main reasons. Autism spectrum disorders have been consistently linked with gross and fine motor dysfunction, and current research suggests that movement indicators may one day be established and used to aid in the diagnosis of ASD. This potential use is significant given that early diagnosis of ASD has been linked to better outcomes later in life, and that ASD affects a significant portion of the United States' population. The following section provides background on ASD and expands on these three justifications.

1.2 Introduction to Autism Spectrum Disorders

Autism is a heterogeneous, neurodevelopmental syndrome characterized primarily by impairments in social behavior and motor skills. The Diagnostic and Statistical Manual, 4th edition (DSM-IV) defines general behavioral indicators for the diagnosis of autism that include qualitative impairments in communication, impairments in social interaction, and repetitive and stereotyped patterns of behaviors (American Psychological Association, 2000). These traits appear in childhood by three years of age, although autism may continue undiagnosed until social demands placed on the child exceed his or her abilities.

The condition was originally described by Leo Kanner, M.D. (1943), based on his own clinical cases. Autism is currently recognized as part of a spectrum of disorders that include Asperger syndrome, Rett syndrome, childhood disintegrative disorder, and pervasive developmental disorder - not otherwise specified (PDD-NOS;

American Psychological Association, 2000). These conditions are collectively known as *autism spectrum disorders*.

Throughout the 1980s, ASD frequency was tabulated at five cases per 10,000 persons, and the conditions were considered a rare clinical occurrence rather than a significant public health problem (Newschaffer et al., 2007). Currently, the Centers for Disease Control (CDC) recognize that one out of 110 children are diagnosed with ASD (CDC, 2006). More inclusive diagnostic criteria and increased vigilance for ASD are factors that have contributed to the increase in this number. Regardless, autism carries significant societal and cost burdens in the United States.

Over a lifetime, the cost of treatment and support for an individual with ASD is estimated to range from 2.5 million to 3.2 million dollars (Jarbrink & Knapp, 2001; Ganz, 2007). This figure includes direct costs, such as medical expenses, and indirect costs, including loss of productivity of caregivers. The yearly societal cost to treat all of the individuals diagnosed with ASD exceeds 35 billion dollars (Ganz, 2006). The Autism Society poses that early diagnosis and intervention could reduce this figure by two-thirds (Autism Society, n.d.). A study completed by Jacobson and colleagues (1998) estimates that early intensive behavioral intervention (EIBI) produces per child savings up to \$200,000 between the ages of 3 and 22 years and up to one million dollars from the ages of 3 to 55 years. A more recent study completed in Texas compared the costs of 18 years of special education to three years of EIBI. The researchers calculated that the state would save \$208,500 per child over the course of 18 years applying EIBI over special education (Chasson, Harris, & Neely, 2007).

While EIBI incurs a larger expense than special education during the three years of treatment, the researchers note that the better outcomes documented in studies by Lovaas (1987) and Sallows and Graupner (2005) quickly recoup the cost, with the majority of children moving into standard classrooms. Inherently, an important component of EIBI is being able to identify the presence of ASD in children as early as possible.

Using the core symptoms as a guideline, assessments have been developed to diagnose children with ASD. While these assessments, including the Autism Diagnostic Observation Schedule (ADOS) and Autism Diagnostic Interview-Revised (ADI-R), are effective in diagnosing autism, they are unreliable for infants under 18 months and demand that a trained professional familiar with ASD administer the tests. The ADI-R requires that the infant have a developmental age of at least 18 months, while the publisher of the ADOS advises caution when interpreting scores of children with developmental ages younger than 18 months (Lord, Rutter & Le Couteur, 1994; Western Psychological Services, nd). Worth noting is that a child suspected of having ASD will often be chronologically older when they reach a developmental age of 18 months, delaying a possible diagnosis of ASD. The nature of the assessments are such that the disorder can only be diagnosed after the symptoms have fully manifested, although earlier subtle indicators, such as motion, may be present.

Following diagnosis, the current treatment paradigm for ASD relies on early, intensive behavioral intervention to achieve the best possible outcome for children

with ASD. Therefore, earlier diagnosis allows for an earlier implementation of treatment intervention and ultimately a better outcome for the child. (McEachin, Smith, & Lovaas, 1993; Moore & Goodson, 2003; Sallows & Graupner, 2005)

A potential method for earlier ASD diagnosis lies in movement. Although the core characteristics of ASD are qualitative impairments in communication and social behavior, motor abnormalities have largely been accepted as associated symptoms. Numerous studies show that ASD-affected children and adults, ranging in age from 7 to 32, display poor upper- and lower-limb coordination, leading to abnormalities in attaining major motor milestones and performing fine motor tasks (Bhat, Landa, Galloway, 2011). In infants, studies show that individuals diagnosed with ASD display consistent differences in their motion, compared to typical children of the same age, when performing actions such as sitting, crawling, and lying down (Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998; Ozonoff et al., 2008; Wetherby, Woods, Allen, Cleary, Dickinson, & Lord, 2004). More details on such studies are provided in the Literature Review section.

In addition to the potential for a novel method of diagnosis, a current theory exists that movement abnormalities in infancy contribute to later social impairments in individuals with ASD (Bhat, Landa, Galloway, 2011). For example, joint attention – the process of responding to social initiation from others – may be made less effective by slow or uncoordinated head, arm, and eye movements (Gernsbacher et al., 2008). This early social impairment may then inhibit later formation of strong peer networks and integration into social settings. Therefore, understanding and

enhancing motor performance of infants with ASD may also contribute to better outcomes later in life. For this reason, additional impetus exists to further investigate the link between ASD and movement, especially using our novel motion capture design.

1.3 Purpose of Study

The purpose of this study was to determine if passive motion capture technology can be used to investigate the movement of infants at risk for ASD. Motion capture represents a new and unique method for studying the physical manifestations of ASD, allowing researchers to evaluate current methods and develop new techniques for diagnosis and treatment. However, there is currently no published information regarding the use of passive motion capture technology with infants at high risk for ASD. To fill this gap in the knowledge base, this study acts as a proof of concept piece demonstrating the effectiveness of using a passive motion capture system to study the movements of infants at high risk for ASD.

1.4 Methodology Overview

1.4.1 Research question

In order to determine if passive motion capture is a viable method for researching infants at risk for ASD, this study sought to answer the following question - What quantifiable differences in the movements of infants at high and low risk for ASD can passive motion capture technology detect?

1.4.2 Experimental and control groups

The infant participants, aged 6 to 12 months, were divided into the high-risk experimental group and low-risk control group, based on whether or not they had an older sibling diagnosed with ASD. Infants with an older sibling diagnosed with ASD are 20 times more likely to develop ASD, or some form of developmental delay, than those in the background population (Merin, Young, Ozonoff & Rogers, 2006). Low-risk control infants did not have any older siblings diagnosed with ASD. The final population for this study included nine low-risk infants and three high-risk infants.

1.4.3 Motion capture system

To analyze the participant movements, the NaturalPoint OptiTrack motion capture system was used with a 12-camera setup. Data were recorded with the Tracking Tools software. As described earlier in the Introduction, a custom suit was designed and code was written to adapt the hardware and software for use with infants.

1.4.4 Tasks

Infant participants performed four tasks: pull-to-sit, reach-to-grasp, visual tracking, and postural control. In the pull-to-sit task, a researcher grasped the infant's hands and pulled him from a supine to a sitting position. During this motion, several motion indicators were measured, including the average and maximum degree of head lag. In the reach-to-grasp task, a supine or seated infant started with hands at his sides and reached toward a cylindrical toy held in front of him in a horizontal or vertical orientation. During the reach, average and maximum hand velocity were

among the indicators measured. The visual tracking task consisted of a toy being moved from directly in front of the infant to 90 degrees to his left, back 180 degrees to his right, and finally back to his center. The deviation of the infant's head to the toy was studied. During postural control, the infant was first given a light object to play with for thirty seconds, and then given a heavy object with the same shape. The ability of the infant to maintain his posture when he received the heavy object was measured by the change in shoulder stability relative to the stomach.

1.5 Conclusions

Results showed statistically significant differences between the two populations in movement indicators in the reach-to-grasp task, demonstrating that our motion capture system and suit design are capable of discerning subtle differences in motion. The left hand horizontal reach differed across our populations, ($p = 0.040^{**}$), the right hand horizontal reach also differed ($p = 0.027^{**}$), as did the right hand vertical reach, ($p = 0.002^{**}$). However, significant limitations existed that require repetition of this study to demonstrate the reliability of our system. These include small sample size and high levels of unusable data. No usable data were obtained for the postural control task, and only one high-risk trial was analyzable for visual tracking due to issues such as marker occlusion, point flickering, and point jumping. Specific changes in suit design, task execution, and data analysis are discussed in this thesis that could resolve these problems in another repetition of this study. Despite these limitations, this research produced a novel suit design and point labeling

algorithm that contribute to the knowledge base required to further the use of motion capture research to determine movement indicators for ASD.

Chapter 2: Literature Review

2.1 Background on ASD

Autism is a heterogeneous, neurodevelopmental syndrome characterized primarily by qualitative impairments in communication and social interactions, as well as repetitive, restricted behaviors and activities (Rellini, Tortolani, Carbone, & Montecchi, 2004). The Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revised (DSM-IV-TR) classifies autism under the category of autism spectrum disorders, which includes four more conditions – Asperger syndrome, Rett syndrome, childhood disintegrative disorder, and PDD-NOS (APA, 2000). All five disorders present with similar core symptoms, and the etiology of conditions on the autism spectrum remains largely unknown, with the exception of Rett syndrome (APA, 2000; National Institute of Neurological Disorders and Stroke, 2009).

2.1.1 Prevalence

First described by Leo Kanner in 1943, the prevalence of autism is just now being realized. Throughout the 1980s, ASD frequency was tabulated at five cases per 10,000 persons, and the conditions were considered a rare clinical occurrence rather than a significant public health problem (Newschaffer et al., 2007). Current research estimates that one out of every 110 children fall within the autistic spectrum, making ASD the most common pediatric diagnosis in the United States. (CDC, 2006; Fombonne, 1999).

2.1.2 Current Methods of Diagnosis

Autism spectrum disorders are diagnosed through structured caregiver interviews, standardized assessments, and direct observation to determine if a child meets DSM-IV-TR criteria. A degree of variability exists, however, with differences in training, professional background, regional tendencies, access to specialists, availability of tools, and conceptual preferences of evaluators leading to imperfect diagnoses (Rosenberg, Daniels, Law, Law, & Kaufmann, 2009). These imperfections are further compounded when making ASD diagnoses at young ages. Reliable diagnosis typically occurs between three and six years of age (Wiggins, Baio, & Rice, 2006). Indeed, Charwarska and colleagues (2007) found that diagnosis based on the ADI-R, a widely used structured parent interview, was not reliable in infants younger than 24 months old. Approximately half of diagnoses made using the ADI-R agreed with the clinical diagnosis.

2.1.3 Treatment/Intervention

After diagnosis, healthcare professionals can prescribe intensive behavioral treatment or medication to minimize negative behaviors and to further develop social and motor skills. Early identification of autism is critical, however. Studies have shown that a correlation exists between the age that treatment begins and the quality of life that ensues – a child that begins treatment earlier has a better chance of leading a life well assimilated into society (Willis, 2006). Researchers also suggest that treatment implemented after the age of five is unable to prevent the establishment of behaviors characteristic of ASD (Naimer, Alonim, Tayar, & Schipper 2006). This

research highlights the importance of early diagnosis in outcomes for children with ASD.

2.1.4 Movement Abnormalities in ASD

Although social impairments are the primary characteristic of ASD, atypical movement and motor deficits are associated symptoms. Hans Asperger's initial description of "childhood autistic psychopathy" noted clumsiness as one of the common symptoms in 1944 (Boucher, 2009). Asperger's syndrome is considered to be under the umbrella of ASD in DSM-IV-TR. Studies show that ASD-affected children and adults, ranging in age from seven to 32, display poor upper and lower-limb coordination, leading to delays in attaining major motor milestones and abnormalities performing fine motor tasks. For example, gait has been studied extensively in individuals with ASD, and studies have shown varying, abnormal patterns that include lack of heel-toe pattern, poor balance, lack of reciprocal arm movements, and a waddling gait (Bhat, Landa, Galloway, 2011; Mari, Castiello, Marks, Marraffa, & Prior, 2003).

Another characteristic motor abnormality of individuals with ASD is the prevalence of repetitive, stereotyped motions. Examples include rocking and arm waving, as well as those given in DSM-IV-TR: hand or finger flapping or twisting or complex whole-body movements (APA, 2000). Repetitive movements with objects and body distinguished infants in the second year of life who were later diagnosed with ASD, from typically developing and developmentally delayed infants (Wetherby, Woods, Allen, Cleary, Dickinson, & Lord, 2004). Morgan and colleagues (2008)

further examined stereotyped movements in CSBS-DP videotapes of 18- to 24-month-old infants who were later diagnosed with ASD after 30 months of age. Their study found that participants with ASD demonstrated a significantly higher rate of repetitive, stereotyped motions than unaffected individuals in the control group. However, Loh and colleagues (2007) found that many such motions are often exhibited by typically developing infants, and are therefore less pronounced in infant siblings of children on the ASD spectrum. For this reason, the four tasks analyzed in our study do not focus on repetitive and stereotyped motions, which are nonetheless an important part of the ASD phenotype.

The following sections describe the progress of research regarding movement and ASD and then cite previous studies relevant to the four motion tasks used in this study.

2.2 Progress of ASD Research

Since the late 1970s, research began to indicate that motor function may not be intact in individuals with ASD, which was then defined differently than ASD is today in DSM-IV-TR. These early studies largely employed retrospective designs – researchers analyzed old videos of individuals with confirmed autism diagnoses and used various systems to characterize movement. For example, Teitelbaum and colleagues (1998) assigned spherical coordinates to body segments, per the Eshkol - Wachman Movement Analysis System, to analyze the motion of infants with and without ASD in home videos. Their results showed distinct differences in lying down, crawling, sitting, and walking (Teitelbaum et al., 1998).

More recently, with growing interest in using motor characteristics in infancy as possible diagnostic markers for ASD, researchers have performed prospective studies comparing infants at high and low risk for autism. Because such designs can be more strictly controlled, researchers can collect empirical data with less bias. Individuals considered at high risk for ASD include children with early signs of developmental delay, children with genetic anomalies, or individuals with siblings previously diagnosed with ASD (Zwaigenbaum et al., 2006). The latter represents the most clearly defined high-risk group – younger siblings of children with ASD are approximately 20 times more likely to develop ASD than the general population and face a 25 to 50 percent higher risk of displaying milder social and behavioral impairments (Yirmiya et al., 2006). For this reason, we chose to study infant siblings of children diagnosed with ASD.

A second important paradigm shift in movement and ASD research has been the gradual acknowledgement that IQ may not solely determine the degree of motor impairment in infants with ASD. Early studies, such as Manjiviona and Prior (1995) and Ghaziuddin and Butler (1998), provided evidence that motor delays in children with ASD were a product of their cognitive ability, with children with lower IQs found to have more motor deficits. However, a study completed by Jansiewicz and colleagues (2006) paints a different picture. In this study, the researchers wanted to focus on children with ASD without associated mental retardation, thus they only accepted participants with a Full Scale IQ greater than 80. With this IQ cutoff, the researchers still observed large motor deficiencies in the ASD group compared to the

control group (Jansiewicz, Goldberg, Newschaffer, Denckla, Landa, & Mostofsky, 2006). Results of this study indicate that motor skills are independent of IQ or cognitive ability.

Third, a theory has recently emerged among many researchers that early motor abnormalities may significantly contribute to the later social impairments that characterize ASD. Typical coordination and movement are necessary for children to engage in social interaction and build strong peer networks. Early difficulties in social response and engagement, caused by slow, uncoordinated movements, may therefore contribute to the later impairments in communication that is a diagnostic criteria for ASD (Bhat, Landa, & Galloway 2011). Therefore better understanding autistic motion could not only help create diagnostic indicators, but could also contribute to treatment of the condition's social impairments.

We now describe the research basis for using the four tasks investigated by this study and the various indicators.

2.3 Tasks Indicative of Motor Abnormalities

2.3.1 Reach-to-Grasp

A person's ability to reach for and grasp an object is a complex motion, used often in daily life and considered a major motor milestone in development. The task involves significant planning – the individual must extract spatial information to determine the reach, and then must translate stimuli about the object's size, shape, and weight to perform the grasp. Many previous studies have characterized this motion,

indicating that both portions go through two different neural channels that work together. Finally, in humans these motions are not present at birth. By approximately nine months of age, infants begin to exhibit reaches and grasps with precise distance, direction, and hand-shape (Mari et al., 2003).

Several previous studies have shown atypical reach and grasp movements in individuals with ASD. Mari and colleagues (2003) used an ELITE motion capture system to characterize the reach and grasp movement of 20 participants with ASD and 20 age-matched controls, who were asked to reach and grasp two objects of different sizes placed at two different distances. They found that children with ASD and an IQ less than 75 performed the reach more slowly, with a lower peak velocity, longer deceleration time, and later initiation of the grasp, than typical children and autistic children with IQs higher than 75. A later study by Glazebrook and colleagues (2006) did not find a correlation between IQ and arm movement.

One possible explanation for these results lies in the idea that children with ASD exhibit deficiencies in motor planning. In a 1996 study, researchers employed a simple “reach, grasp, and place” task. Participants with ASD were significantly more likely to place their arms in an uncomfortable position after the task, indicating an inability to plan effectively (Hughes, 1996).

2.3.2 Pull-to-Sit

Research specifically looking at motions in ASD during a pull-to-sit movement is sparse, but anecdotal findings and experimental evidence indicate that useful indicators could be extracted from this task. The 2011 finding by Bhat and

colleagues discussed above points to lack of head-holding as a potential motor abnormality in children with ASD. Indeed, clinicians have often anecdotally cited increased head lag in patients with ASD (Rebecca Landa, personal communication, Oct. 27, 2009). In a study currently going to press, Flanagan and colleagues investigated head lag using the Mullen Scales of Early Learning. Coders assigned the score “0” when the infant maintained the head in alignment with the spine, and the score “1” when any degree of head lag was observed. In a sample of 40 high-risk infants studied longitudinally from 6 months to 36 months, at which time reliable autism diagnosis could be made, the researchers found that head lag at six months was significantly associated with ASD at 36 months. The study also compared two samples of 20 high-risk and 21 low-risk infants, finding head lag to be more frequently observed in high-risk infants.

2.3.3 Visual Tracking

Visual tracking is a complex movement that allows an individual to follow the movement of objects through space. In following moving objects, individuals are required to use visual reception skills, including spatial organization. Spatial organization is a cognitive process that allows for individuals to follow simple movement patterns through space while maintaining their orientation.

In discussing the development of the Autism Observation Scale for Infants (AOSI), an observational diagnostic method currently used in identifying autism, Bryson and colleagues (2008) mention that clinical experience led to the inclusion of a visual tracking task in the AOSI. After compiling data from retrospective parental

reports and clinical case studies, Bryson and colleagues determined that the inability to visually track a laterally moving object across the midline of the body is indicative of autism (Bryson, McDermott, Rombough, Brian & Zwaigenbaum 2000; Bryson, Zwaigenbaum, McDermott, Rombough & Brian, 2008). In a prospective 2005 study, Zwaigenbaum and colleagues identified atypical eye contact, abnormal visual tracking, and visual attention disengagement as three of many behaviors that at 12 months of age, predicted an autism diagnosis at 24 months in a sample of seven children. Zwaigenbaum and colleagues (2005) indicated that visual tracking, disengagement of attention, and gross motor control were different between individuals with autism and typical individuals. They conducted this study with 150 high-risk infants, providing a large sample size lacking in many other studies dealing with this population.

2.3.4 Postural Control

Postural control, sometimes referred to as postural stability, is a person's ability to maintain balance and orientation against gravity. Postural control is especially important in maintaining the body's stability while moving or performing tasks (Massion, 1994). While an ongoing developmental process, postural control undergoes a major transition at six months of age when infants move from the primary variability stage to secondary variability (Hadders-Algra, 2005). In primary variability, few muscles participate to stabilize the infant, leading to a very limited ability for the infant to adapt to their environment to maintain their posture; in secondary variability, the infant's ability to respond to their environment increases,

giving the infant more latitude to maintain balance (Hadders-Algra, 2005). The phenomenon of postural control has been explored extensively in school-age children and adults.

Early studies investigating the relationship of autism and impaired postural control involved autistic individuals with mental retardation (Kohen-Raz, Volkmar, Cohen, 1992; Gepner, Mestre, Masson, de Shonen, 1995). While these studies were able to establish a link between mentally retarded individuals with autism and deficient postural control, it was not until a study performed by Minshew and colleagues in 2004 that researchers were able to directly link autism with impaired postural control. Minshew and colleagues compared the postural control ability of autistic individuals aged five to 52 years old with non-autistic, age-matched individuals under various conditions, including varying floor stability as well as normal and obstructed visual input. They used dynamic posturography to compare 79 individuals with ASD to 61 typical individuals. By having the participants stand on a force plate, Minshew and colleagues were able to measure the degree of sway of each participant under the varying conditions. Ultimately, the study determined that individuals with ASD distracted by several sensory inputs at once had significantly less postural control than their age-matched peers (Minshew, Sung, Jones, & Furman, 2004).

Research has been much more limited into postural control in infants. In an analysis of infant home videos of children later diagnosed with autism, Teitelbaum and colleagues (1998) identified postural deficits when the infants were sitting.

Typical infants are able to maintain a sitting posture at approximately six months of age even when they are reaching and playing with toys or otherwise moving. In the infants later diagnosed with autism, the researchers observed extreme cases where the infant simply fell over when in a sitting position and did not make any attempt to brace themselves as they fell. In other milder cases, the infant could remain upright but would topple if he or she reached for an object or otherwise moved the trunk or arms. The researchers in this study also identified postural or movement abnormalities in the infants later identified with autism relating to lying, moving from a supine to prone position, crawling on hands and knees, standing, and walking (Teitelbaum et al., 1998). A more recent study completed by Bhat and colleagues (2011) noted that infant siblings of children diagnosed with autism have a lack of head-holding and rolling at three months and a lack of pivoting and side-prop postures at six months.

2.4 Motion Capture Technology

Quantitative analysis of the described tasks requires three-dimensional motion capture. While there are many types of motion capture systems available, the systems have varying potential applications based on their advantages and disadvantages.

2.4.1 Motion Capture System Types

As described in the Introduction, motion capture systems have been used to characterize and compare movement to better understand a variety of clinical conditions, including Parkinson's Disease, ASD, or trauma after an accident. When

movement is studied, it is crucial that the researcher is able to move the image around and study it from multiple viewpoints. Thus, a three-dimensional motion capture system is often used.

Movement analysis in three dimensions requires fundamental information including angles and rotations between body parts, the starting, intermediate, and ending positions of points on the body, and a relative frame of reference (Kiser, 2010). The data from the motion capture are translated into moving geometric objects or lines, from which measurements can be extracted. For example, in a motion analysis of two body parts, each is known as a segment. Each segment possesses unique properties including size, mass, and length, and is usually viewed as a variation of a geometric object (Kiser, 2010). The point where two segments intersect is known as a joint, from which joint angles can be measured. In most capture systems, the user is able to define their own custom segments. A fixed point is designated as the origin of the laboratory – i.e. point (0,0,0) in an (X,Y,Z) coordinate system.

Many different types of motion capture systems exist for different tasks and objectives; among these two common techniques are marker-less systems and marker-based systems. Marker-less systems can recognize edges of a subject's body and create geometric segments (Kiser, 2010). As described in the Introduction, one type of marker-less system is an inertial system, which uses gyroscopes to collect and transmit rotational data to a computer.

In systems without markers, however, clothing can create distortion of the geometric segment, and thus must be form-fitting, the rotations of segments are difficult to observe, and small segments such as hands are particularly difficult to track (Kiser, 2010). This type of system is still evolving, but may be useful in situations where placing markers on a subject is not feasible or practical.

The majority of motion capture systems are marker-based. In order to accurately define a segment's movement, markers are placed on a body part to create non-ambiguous definitions of segment location and geometry. The system then tracks and calculates the locations of these markers.

Two types of marker-based systems exist: active and passive. An active marker is able to convey information about itself to the system and requires a power source and a means of communicating with the system; these include flashing LED's, inertial sensors, and electromagnetic sensors (Kiser, 2010). A passive marker, on the other hand, does not require an internal power source and is simply a reflective point that the system can track.

A passive marker system, which is the type used in this study, has two components: cameras and reflective markers. The cameras emit infrared light, and a ring of LEDs around each camera lens receives reflections back from the markers. Three cameras can use these signals to triangulate the location of a marker's center. By tracking the movement of three or more markers, passive optical systems can model the movement of entire limbs.

These systems require a calibration step before they can start recording movement. An L-shaped calibration tool with markers attached to it, called the ground plane, is placed on the floor so that the cameras can establish a coordinate system in the laboratory. The next step is to use a calibration wand with markers placed in known positions to establish the motion capture volume. The wand is waved around the area for the cameras to focus on the markers, calibrate, and correct for lens distortion. In general, infrared cameras record subjects with reflective markers and are ideal for work in outside lighting and large volumes. Some limitations of this type of system include the possibility of marker occlusions during data collection, the requirement for volume calibration, and the possibility of lengthy marker setup time.

In this study, the OptiTrack camera system was used with Tracking Tools software. The latter is a real-time, three-dimensional optical tracking program that offers calibration, three-dimensional reconstruction, and tracking of rigid bodies in tandem with an OptiTrack camera system. Rigid bodies are unique configurations of reflective markers with determined relations that allow identification and tracking in three-dimensional space. Rigid bodies on objects that are to be tracked must be defined by the user, and the definitions depend on numerous factors including capture volume, camera arrangement, and the object's size. Usually, at least three markers are necessary to define a rigid body. However, the use of more markers in the rigid body can help increase precision and prevent rigid body flipping.

In the OptiTrack system, spherical reflective markers typically produce the most accurate and stable data, and lead to less errors when calculating their center of

mass and position. Marker size ranges anywhere from 3 to 25 millimeters. When small rigid bodies are necessary, it is better to use smaller markers for reduced marker occlusion, which occurs when a marker blocks another from the camera's view. When markers are tracked from longer distances, larger markers are recommended to increase resolution. In addition, markers should not be placed too close together because if they are less than 6 mm apart, marker occlusion is more likely.

Multiple OptiTrack cameras are placed in the lab so that they have overlapping fields of view and are positioned at different angles. This creates an area called a capture volume, where the reflective markers can be tracked. To enhance camera precision and ability to track markers, they are connected together using Sync Cables, which allow the cameras to synchronize exposure timing. The optimum distance between tracking markers and the cameras lies between 0.5 and 6 meters. The tracking environment should also be void of all reflective materials in direct view of the cameras.

2.4.2 Use of Motion Capture in Research

2.4.2.1 Disease Associated Study with Motion Capture Technology

Motion capture technology has been used in past studies to identify disease-related abnormalities in movement. These abnormalities allow for better understanding of their associated conditions, sometimes leading to new treatment techniques. Perhaps one of the most researched conditions is Parkinson's disease, for which several studies are described below.

In Parkinson's disease, postural instability is used as an indicator of the disease's progression, where postural instability is defined as the inability to maintain body balance (Madete et al., 2011). In a 2009 study, Johnsen and colleagues studied the effect of bilateral deep-brain stimulation of the subthalamic nucleus on the postural stability and gait of eight individuals with Parkinson's disease and twelve healthy controls. The subjects' gaits were observed using the PlugInGait model with the Vicon 612 motion capture system. This setup consisted of eight infrared and two digital cameras that measured 39 retro-reflective markers placed on the individual. Subjects were asked to walk barefoot along a walkway for ten meters, while kinematic data describing the spatiotemporal features of gait, and forces acting upon and produced from the body during gait were measured and subsequently analyzed. The technology was used to identify whether a patient's stride was symmetric by measuring the distance between heel position and the body's center of mass. Deep-brain stimulation improved the patient's ankle push-off, which increased the distance between heel position and the body's center-of-mass and resulted in reduced asymmetry in gait. Studying the effects of this treatment with motion capture technology allowed the researchers to conclude that deep-brain stimulation of the subthalamic nucleus greatly enhances motor functions and balance, validating its therapeutic potential for Parkinson's disease (Johnsen, Mogensen, Sunde & Ostergaard, 2009).

In 2006, the effect of bilateral reaching tasks on hemiparetic arm motor control was studied in twenty stroke patients using the Visualey Hardware three-

dimensional optical motion capture system created by PhoeniX Technologies, Inc. (Chang, Tung, Wu, Huang, & Su, 2006). These individuals are prone to neurological deficits arising from stroke-related vascular injury to the brain, which may lead to impaired motor function, mostly in upper extremity movements. The movement trajectories of the affected arm and trunk were measured by marking fourteen anatomical landmarks with infrared light emitting diodes. The patients were asked to perform three movement tasks in a random sequence, including reaching forward with the affected limb, reaching forward with both limbs and reaching forward with both limbs and an inertial load of 25 percent upper limb weight added to the unaffected limb. The resulting kinematics data included information such as maximal velocity, percentage of reach at maximal velocity, movement time, and number of movement units, and were analyzed by the VZAnalyzer software. The study concluded that bilateral arm movements can potentially serve as a form of treatment for individuals undergoing stroke rehabilitation (Chang et al., 2006). The results of this study illustrate the wide-range of applications of motion capture technology for studying human movement.

More recently, Madete and colleagues (2011) used a passive optical motion capture system to analyze the gait of hemiparkinsonian rats, with the aim of identifying new treatment methods for Parkinson's disease. Motor deficits, including postural instability, result mainly from neurodegenerative processes in the brain that decrease levels of dopamine (Madete et al., 2011). In order to simulate motor deficits analogous to those displayed in human Parkinson's disease, the

researchers injected the rats with neurotoxin 6-hydroxydopamine. They explored the effects of dopamine depletion on the movement of rats while walking on beams of differing widths using an optoelectronic camera system (Qualisys, Sweden). Three-dimensional Cartesian data were obtained from markers attached to the rat. To quantify postural stability, body displacement and orientation were calculated. The results of this study demonstrate a new approach to using passive-marker-based motion capture technology to quantify postural instability for rats in a Parkinson's disease model.

2.4.2.2 Infant Studies with Motion Capture Technology

Use of motion capture technology has also been extended to studying infant movements. In 2010, Zentner and Eerola examined the effect of musical and rhythmic stimuli on a sample of 120 infants between 5 and 24 months old. In one phase of the study, two important movement variables, velocity and acceleration of reflective markers, were studied using five Qualisys Pro Reflex cameras at 60 frames per second temporal accuracy. The Qualisys Pro Reflex system is a passive marker-based motion capture system that uses reflective sphere markers and infrared cameras. Three to eight reflective markers were attached to each infant. This study found that infants exhibit more significant rhythmic movements in response to musical patterns than to human speech. In addition, infants showed flexibility in movements according to different musical tempos (Zentner & Eerola, 2010).

The following two studies examined motions similar to our study's reach-to-grasp and postural control tasks. In 2010, Berthier and Carrico investigated infant

performance during a reaching task similar to our study's reach-to-grasp action. Fifty-six infants were studied at six months, nine months, and 12 months of age. The study used the Northern Digital Optotrack motion analysis system with infrared cameras. Two reflective markers were placed on each infant's right wrist, and one was placed on the shoulder. The researchers aimed to assess infant ability to make multiple corrective movements during a task, which previous studies state is lacking before 12 months of age. Berthier and Carrico's findings aligned with this literature.

A third study looked at the postural control of infants who were not yet able to sit independently by themselves. Hopkins and Ronnqvist (2002) examined 11 infants at the ages of five months and six months, all of whom could not sit alone for more than five seconds. In the study, participants sat on commercially available infant chairs or on modified chairs that encouraged spinal extension. A target object was presented to both groups, and each infant's postural control was examined while she reached for the object. Three 120 Hz MacReflex System cameras tracked two reflective markers on the infants' wrists, one reflective marker on the infants' heads, and one on the backs of the chairs. Hopkins and Ronqvist found that infants displayed better kinematics during the reach task if they had the additional lower body support from the modified chairs (Hopkins & Ronnqvist, 2002).

2.5 Lab settings of infant studies

In studies using motion capture technology with infants, including those detailed above, several common practices exist that are briefly discussed. Several studies use video cameras, in addition to the capture cameras, to record their sessions.

These recordings can be used in data analysis to aid in matching the data points output by the software to the markers on the participant's body. In addition, the recordings can be coded according to various scales to yield useful information. For example, Eerola and Zentner (2002) coded participant videos to identify special rhythmic movements in which a motion is repeated three times at short intervals.

The most common child motion capture suits are designed for children aged 10 to 12 years. Thus, past infant studies that use motion capture technology have put the reflective markers directly onto the infants' body parts. Though not every study specified the placement of the reflective markers on infants, most of the indicated arrangements used three to eight reflective markers. During infant reaching tasks, the reflective markers were placed on the infant's wrists and shoulders (Berthier and Carrico, 2010).

2.6 Developmental Assessments

2.6.1 Rothbart Infant Behavior Questionnaire

Originally developed by Mary K. Rothbart in 1981, the Rothbart Infant Behavior Questionnaire (IBQ) is an established, reliable method to measure several dimensions of child temperament, which Rothbart defined as individual differences in reactivity and self-regulation. Early differences in infant temperament have been linked to later personality and social development, creating the need for an empirical, non-biased method to measure this characteristic.

In her original study, Rothbart used conceptual analyses, item analyses, and tests of reliability and stability to establish scales to measure the following dimensions of temperament – activity level, smiling and laughter, fear, distress to limitations, soothability, and duration to orienting (Rothbart, 1981).

A 1986 study by Rothbart yielded data that provided additional validation support for use of the Rothbart IBQ. This research followed 46 infants through three, six, and nine months of age. At each time point, mothers filled out the Rothbart IBQ, and researchers observed and coded child behavior during bath, feeding, and play. At three months, the two types of data showed convergent validity for the following five temperament dimensions: activity level, smiling and laughter, distress to limitations, fear, and vocal activity. At six and nine months, the data showed convergent validity for four of the five scales (Rothbart, 1986).

In 2003, Gartstein and Rothbart revised the IBQ to include nine additional scales of measurement and to modify seven previous scales. This latest version – the Rothbart IBQ-Revised (IBQ-R) – was used in this study.

2.6.2 Communication and Symbolic Behavior Scales Development Profile

In 2001, Wetherby and Prizant created a routine developmental screening for children six to 24 months called Communication and Symbolic Behavior Scales Developmental Profile (CSBS-DP). This screening was designed to detect early signs of communication delays and to decide the need for further communication evaluation. CSBS-DP focuses on seven language predictors to assess communication competency:

The seven predictors include emotion, understanding of words, and use of eye gaze, communication, gestures, sounds, words, and objects.

CSBS-DP consists of three components: a one-page checklist, four-page questionnaire, and behavior sample. Each CSBS-DP component focuses on the seven language predictors mentioned above to screen children who are at high risk for developing communication impairment. The checklist and the questionnaire are to be filled out by the children's primary childcare provider. The last behavior sample is filled out by a health professional by looking at the parent-child interaction (Wetherby & Prizant, 2001).

Each component of the CSBS-DP can be used independently or combined with other developmental screenings. In our research, the CSBS questionnaires were given to the parents before the testing sessions (Wetherby & Prizant, 2001).

2.7 Principal Component Analysis

Principal Component Analysis (PCA) is a dimensionality reduction technique that has long been used in studies involving human motion. PCA is not an assessment method, but rather in the context of movement analysis PCA is used to produce a set of "new variables," that are linear combinations of the original values. These new, reduced values can then be used to test hypotheses. Therefore, PCA is a preprocessing tool for analysis. In a study by Black and Yacoob (1997), PCA was used to model several different predetermined "activities", such as walking. After collecting motion data from many participants, a database of descriptors for each action was formed. Then, new instances of the same motions could be successfully

recognized by a computer algorithm comparing the new instance to the stored action descriptors. In other words, the computer learned to recognize actions from examples. That PCA was used to generate a representation of the actions shows that it is useful in the analysis of human motion.

In another study involving PCA, the technique was used to examine X-ray images of human mouths and jaws during speech. More specifically, a guided version of PCA was used, allowing the researchers to select aspects of the motions to analyze separately. The study was able to develop a very consistent model of tongue motion (Busset, Cai, Hirsch, & Laprie, 2009). A third study by Haibin, Qingmin, and Yunqi (2011) developed a face recognition algorithm using PCA. Three-dimensional point clouds representing human faces were broken down into geometric features that were extracted, and could then later be recognized. Their procedure was robust to changes in expression compared to other techniques (Haibin et al., 2011).

Given the previous success with using PCA in the analysis of human motion, we have decided to adopt it as the first step in the analysis of our data.

Chapter 3: Methodology

3.1 Introduction

Our differential study aimed to develop a framework of movement analysis based on motion capture capable of investigating specific motions of infants at high and at low risk for autism. Four tasks - pull-to sit, reach-to-grasp, visual tracking, and postural control - were chosen based on relevant literature suggesting these movements to be different in children with and without ASD. Once the goals and objectives of our study were established, the practicalities of executing our study were addressed: a lab setup was created, motion capture hardware and software were chosen, a custom motion capture suit was designed, and the lab set-up was optimized to yield usable data on the participants' movements.

After these parameters were established, we designed the experiment incorporating our chosen tasks and motion capture system. This study's target age range of 6 to 12 months was too early of an age range for participants to have confirmed autism diagnoses. Therefore the independent variable in our experiment was the "risk level" of the infant participant. An infant was classified as "high risk" (experimental group) if he or she had a sibling with autism and as "low risk" (the control group) if they did not. The dependent variable was the presence of specific motion indicators associated with each of our chosen tasks, such as neck angle and reach velocity, which could be used to distinguish between the experimental and control groups.

Infants were recruited from the College Park community and the greater Baltimore and Washington, D.C., metropolitan areas. Participants completed a telephone screening and several developmental assessment forms. They then followed a standard protocol designed by our team to minimize confounding variables during the motion capture session.

The data obtained from the motion capture session were manually selected from the motion capture software and labeled to represent points on the infant's body using an algorithm we designed. Motion indicators were identified for each task and analyzed using statistical tests and Principal Component Analysis (PCA) to determine what, if any, differences and similarities exist between the high and low risk groups.

3.2 Tasks

3.2.1 Reach-to-grasp

The reach-to-grasp task was chosen for our study because previous research had shown it to represent a complex motion that by nine months of age is characterized by reaches and grasps with precise distance, direction, and hand-shape (Mari et al., 2003). Studies have shown that children with ASD perform the reach more slowly, with a lower peak velocity, longer deceleration time, and later initiation of the grasp as compared to typical children. With this task, three motion indicators can be observed. They are vectors representing the hand velocity and acceleration versus time and concatenation of simpler motion indicators, such as average velocity, average acceleration, and number of movement units of the reaching task (Motion

indicators might be bulleted later on). For the reach-to-grasp task, the primary researcher either laid the participant in a supine position or sat the participant in a seated position on a gym mat, depending on the participant's comfort. The primary researcher first held an object in a vertical orientation at arm's length while the participant's arms were held at his or her sides by the secondary researcher. The participant was then encouraged to reach for the object, with the action beginning when the infant's arms were released. The participant reached for the object with one or two hands and grasped the object, with the action ending when the infant's hand contacted the object. This task was repeated with the toy held in a horizontal orientation. An illustration of the reach-to-grasp task from the supine position can be found in Figure 1, and from the seated position in Figure 2. Motion indicators for this task are average reach velocity and number of movement units. These data are calculated based on movement of the wrist markers of the reaching hand(s). The objects used for this task were cylindrical toys that would maintain the participants' interest and could be held and grasped in both horizontal and vertical orientations. An image of the toy can be found in Figure 3. The motion indicators analyzed in this task included distance vs. time, velocity vs. time, acceleration vs. time, average velocity, average average acceleration, progression units, and movement units (explained in further detail in section 3.9.5).

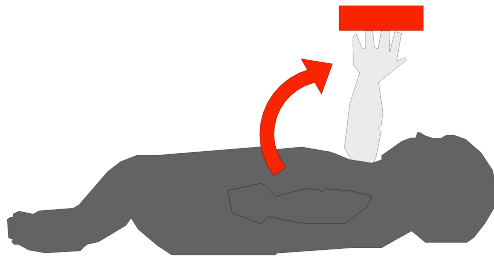


Figure 1: Diagram of reach-to-grasp task from supine position. The researcher held the object, depicted in red, such as a rattle, as featured in Figure 3.

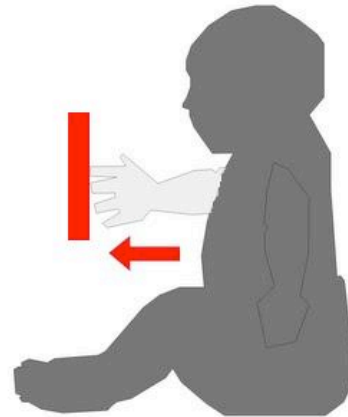


Figure 2: Diagram of reach-to-grasp from seated position. The researcher held the object, depicted in red, such as a rattle, as featured in Figure 3.



Figure 3: Object for reach-to-grasp task. It was important to use toys such as this rattle that could be held for the participant in both horizontal and vertical orientations.

3.2.1 Pull-to-Sit

In the pull-to-sit task, research has suggested that useful indicators can be extracted from it with lack of head-holding existing as a potential motor abnormality in children with ASD (Rebecca Landa, personal communication, Oct. 27, 2009). For the pull-to-sit task, the primary researcher placed the participant in a supine position on a gym mat. The primary researcher then made eye contact with the participant and grasped the participant's hands to pull him or her into a seated position. The action began when the participant's upper back was no longer in contact with the mat and ended when his or her torso was vertical. Infants younger than four months are

usually unable to pull their head up while their torso is being pulled, and so head lag would typically be observed. Figure 4 depicts a typical pull-to-sit, and Figure 5 shows a pull-to-sit with head lag. This behavior disappears for most children by the age of six months, but studies suggest that head lag observed in high-risk infants is indicative of developmental delay. In order to measure head lag, our team measured the angle formed between a vector perpendicular to the plane formed by three markers on the head and the plane formed by two shoulder markers and chest markers. The motion indicators analyzed in this task included neck angle vs. time, mean neck angle, maximum neck angle, neck angle derivative vs. time, maximum derivative, and time ratio of maximum angle (explain in further detail in section 3.9.5).

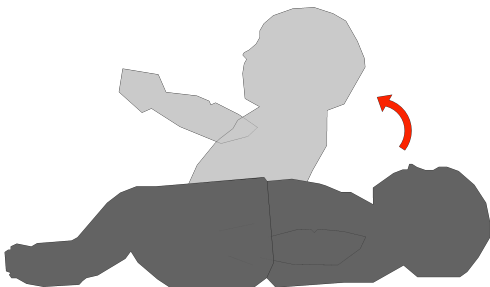


Figure 4: Diagram of typical pull-to-sit task. This diagram depicts the typical motion for an infant at least six months old. The infant's head is aligned with his torso as he is pulled into the sitting position.

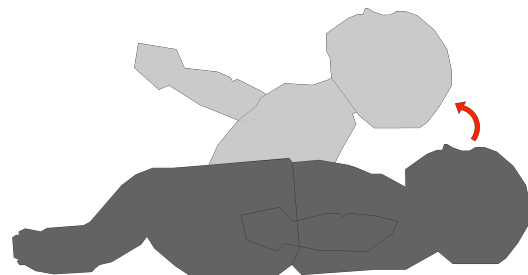


Figure 5: Diagram of pull-to-sit task with head lag. This diagram depicts the pull-to-sit motion when head lag occurs. The infant does not raise his head as his torso is pulled into the sitting position.

3.2.3 Visual Tracking

A visual tracking task was designed to analyze the infant's ability to follow an object through space. Previous research has shown abnormal visual tracking and

visual attention disengagement as two behaviors prevalent in individuals diagnosed with ASD (Bryson, McDermott, Rombough, Brian & Zwaigenbaum 2000; Bryson, Zwaigenbaum, McDermott, Rombough & Brian, 2008; Zwaigenbaum, Bryson, Rogers, Roberts, Brian & Szatmari, 2005).

In this study, the participant was placed in a seated position on the gym mat. The primary researcher held a cylindrical toy with a marker attached (Figure 6) in the center of the participant's line of vision and directed the participant's attention to the object. When the infant was attentive to the object, the object was moved horizontally across the participant's field of vision 90 degrees to the participant's left, and then back across the field of vision 180 degrees to the participant's right, and then back to directly in front of the participant. A diagram of the visual tracking task can be found in Figure 7.

The participant's attention was measured by the angle between the direction the head was facing and the trajectory of the object being tracked.



Figure 6: Object for visual tracking task. The reflector on the object tracked its trajectory as the primary researcher moved it across the participant's field of vision.



Figure 7: Diagram of visual tracking task. The researcher held the object, depicted in red, as featured in Figure 6 to the left.

3.2.4 Postural Control

Previous research has shown impaired postural control in infants and older individuals with ASD (Gepner, Mestre, Masson, de Shonen, 1995; Kohen-Raz, Volkmar, Cohen, 1992; Minshew, Sung, Jones & Furman; Teitelbaum, Teitelbaum, Nye, Fryman & Maurer, 1998). For this reason, a task was designed to gauge the participant's ability to adjust her posture in response to external stimuli.

The primary researcher placed the participant in a seated position. The task required two objects with the same shape and weight-distribution and differing weights. The objects were brightly colored, cylindrical tubes filled with either flour and dried pasta or flour and pennies in order to create the weight difference. The researcher began by offering the participant the lighter cylindrical tube (51.7fstg). After 30 seconds of free play time during which the infant would become accustomed to the lighter weight, the primary researcher removed the first object from the

participant and replaced it with the heavier cylindrical tube (120.7g). The researcher then allowed the infant to play with the new cylindrical tube for an additional 30 seconds. The postural control task is illustrated in Figure 8.

The deformation or control of posture while playing with the heavy object is an indicator for this task. This is measured by shoulder stability of height and orientation above the chest marker. This task required two objects with the same

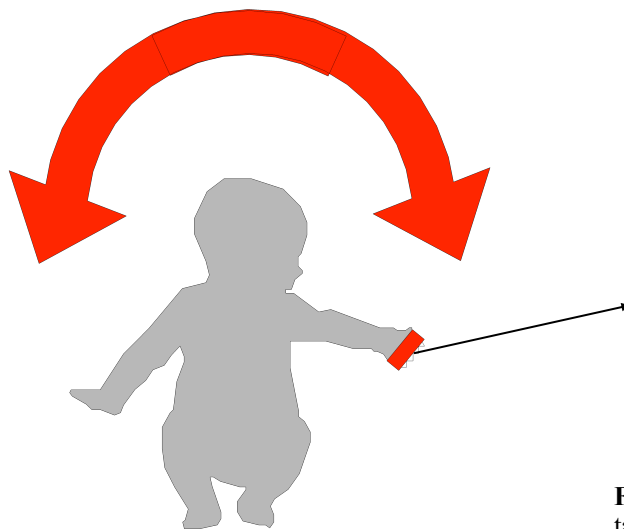


Figure 8: Diagram of postural control task. The researcher presented both of the objects, depicted in red, as featured in Figure 9 to the right, to the participant, in turn.



Figure 9: Objects for postural control task. The two objects had the same appearance, but different masses. Each object would be introduced to the participant by the researcher.

shape but of different weights, as seen in Figure 9.

3.3 Lab Setup

The motion capture lab consisted of 12 infrared Natural Point cameras connected to the lab computer. The cameras were focused on a capture volume, which was a space defined prior to each session by calibrating the system using ARENA software and a calibration wand. This calibration of the volume space was

then loaded into the Tracking Tools software. During the motion capture sessions, the cameras captured and recorded data by reflecting infrared light off of the reflective markers. These data were subsequently recorded in Tracking Tools software because our custom suit did not have the 34-marker configuration required to record data using ARENA software.



Figure 10: Photograph of lab arrangement. Notice the cameras surrounding and facing the gym mat. The doll represents the approximate location of the capture volume, in which the infant would perform the designated tasks.

3.3.1 System Selection

The OptiTrack system with the Tracking Tools software was chosen after considering several factors. First, we decided between inertial, active, and passive systems. As described in the Introduction, inertial and active systems required battery packs housed in the suit, usually on the back of the user. These battery packs would be large and cumbersome, and would inhibit the movement of the infant. Therefore, we decided against both options requiring battery packs. The next issue was to choose a system that had high enough specifications to capture the motions and measure the indicators. However, due to our financial constraints, we decided upon the relatively inexpensive NaturalPoint OptiTrack system with a 12-camera setup.

These cameras had a 640 x 480 pixels (0.3Mp) resolution and operated at 100Hz (OptiTrack, 2011).

The OptiTrack system used the ARENA software, which requires a 34-marker skeleton to collect data and label the points. However, due to the low resolution of our cameras and the small size of our participants, placing 34 markers on a suit resulted in frequent measurement errors because the system could not differentiate between proximate points. As an alternative, TrackingTools recorded all points within the capture volume and output a comma-separated values file. This allowed for a setup with fewer markers, making the infant motion capture feasible.

3.3.2 System Optimization

The lab and motion capture system setup were optimized to create the largest possible capture volume in order to decrease the likelihood of marker occlusion and to minimize the number of potential distractions. To optimize the capture volume, the twelve cameras were arranged along the walls of the lab room and were angled such that each camera focused on the center of the room, where the infant performed the designated tasks. In optimizing the laboratory setup, the cameras were angled as to create redundancy in their respective fields of view. Camera redundancy refers to the phenomenon in which if one camera loses sight of a marker or is blocked during the capture session, other cameras are able to see the lost marker, which maintains the integrity of the collected data. The laboratory setup is shown in Figure 10.

3.3.3 Lab Arrangement

Similar to the camera placement and orientation, the arrangement of the lab during capture sessions was also designed to optimize the quality of the data collected. A diagram of the lab arrangement can be found in Figure 11. The lab was arranged such that the infant participant and primary researcher were placed in the center of the room, with the remaining three researchers as well as the participant's parents or guardians around the periphery of the room. The infant participant and the primary researcher were isolated in the center of the room to maximize the cameras' ability to maintain line of sight with the markers on the infant, which could have been inadvertently obscured by other researchers or individuals sitting close to the participant.

Furthermore, the parents or guardians sat behind the infant participant, out of the participant's view. The parents or guardians were positioned behind the infant so as to prevent the infant from being distracted by her caregivers. The team also took precautions to prevent inadvertent occlusion of the markers. Inadvertent blocking of markers was prevented by designating specific areas for individuals to sit that were determined to be in the background of each camera's field of view. Following the pilot session, an additional consideration was to instruct both researchers and participant parents or guardians to refrain from wearing reflective clothing and jewelry.

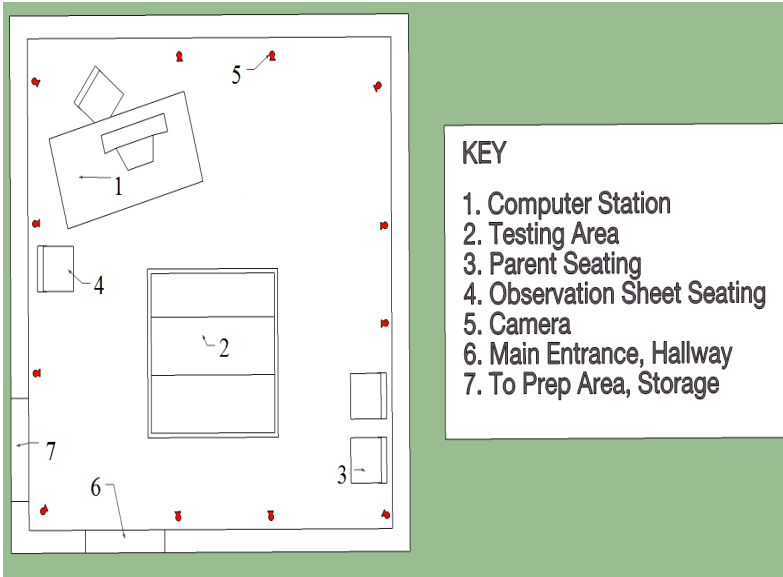


Figure 11: Diagram of lab arrangement. This diagram is a schematic depiction of the crucial elements of the lab arrangement listed in the key. It demonstrates the efficiency of the arrangement in order to capture motion data.

3.4 Suit design

3.4.1 Marker design

The fundamental suit design element for the capture of infant data relied upon the ability of the Optitrack motion capture system to read reflective markers strategically located on the suit. Commercial reflective markers are available for sale through Optitrack, but the sizes of the markers were not compatible with our goal of capturing infant motion capture data, as the smallest commercially-available markers are five-eighths-inch diameter hemispheres (NaturalPoint, 2011). Markers of such large size posed two problems: first, the cameras could not distinguish between two markers in close proximity on our original suit design, and second, the size would be uncomfortable for the infant participants and affect their natural motion. This problem necessitated the design of custom reflective markers.

The original design of the reflective markers was based upon the existing markers our team had encountered, specifically those available through Natural Point.

The design was a hemispherical reflector which we made by covering a 5-mm hemispherical plastic object with reflective dots and reflective tape available through Natural Point. The reflective markers were adhered to the suit using non-toxic adhesive glue dots, attaching the flat surface of the markers to the suit.

Over the course of initial testing with the system and our pilot test, we adapted the reflective markers through several phases. The final marker design was spherical in order to optimize the surface area and ability of the reflectors to reflect infrared light back to the cameras. We maintained the use of the adhesive reflective dots and reflective tape available through Natural Point, allowing our team to mold the reflective tape around smaller spherical objects to create our reflective markers. The final markers were approximately 13 mm in size, allowing us to place several markers strategically around the body, mitigating the two problems of interference and potential discomfort. Figure 12 shows the final marker.

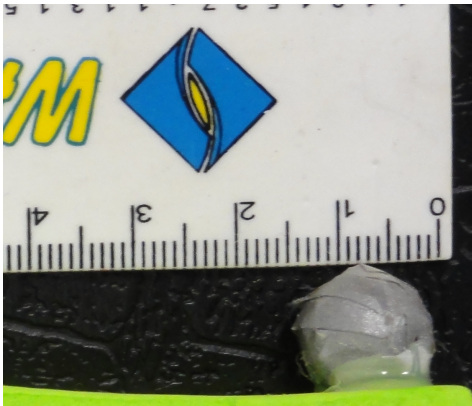


Figure 12: Final reflective marker. Note the spherical design, which maximized reflective surface area, and the size, with a diameter of approximately 13 mm.

3.4.2 Fabrication of suit (materials)

The two high-priority goals in designing the custom infant suit were ensuring the comfort of the infant participants and maximizing the number of reflective

markers incorporated in the design. The suit needed to maximize the infant's comfort in order to minimize any effects on the infant's natural movement. Furthermore, the suit needed to minimize the number of distractions that prevent the infant from focusing on the designated actions. An example of a potentially distracting suit currently being used in research is pictured below in Figure 13.



Figure 13: Motion capture suit in use at University of Miami. Note both the tightly-wound cords which could cause discomfort, affecting natural movement and the blinking lights which could distract the infant.

These goals, as well as our limited budget, led to the decision to design the suit based on customary infant garments, including standard and commercially available bibs, caps, and socks. We customized these garments for use in our sessions by adding a fabric chin strap to the caps and an adjustable, fastenable strap to secure the placement of the bibs. For supplementary points, such as on the elbows, wrists, and knees, we created custom Velcro straps to which we adhered our reflective markers, or originally adhered reflective markers directly to the skin using non-toxic adhesive glue dots.

Further, in addition to modifying the suit to facilitate data collection, the suit also had to maximize infant comfort. For example, one potential cause for infant irritability during the pull-to-sit task may have been the presence of a buckle on the

suit that rested on the infant's back, possibly causing excess discomfort in a supine position. After recognizing the buckle as a potential cause of discomfort, we replaced it with Velcro straps. Following this change to the suit's design, participants seemed to be comparatively less irritated by the pull-to-sit task; however some irritability persisted.

In the original suit design, markers were attached to the suit elements with adhesive dots, but through multiple phases of testing we determined that they were too easy to remove. In the final design, markers were attached to the suit by sewing them into place and securing them with glue. Figure 14 shows the final suit design used during our motion capture sessions.



Figure 14: Final suit design. Note the modified commercially-available bib and cap and the original Velcro wrist straps. On the bib, note modifications including fastenable strap, foam supports, and three reflective markers. On the cap note modifications including the chin strap and three (two visible) reflective markers.

3.4.3 Marker placement

As with the marker design, the suit design went through multiple phases, including a preliminary design phase, several test phases, and a pilot test to refine the suit to maximize its compatibility with the motion capture system. The preliminary marker layout was based on the idea of including as many reflective markers as possible in order to create multiple rigid bodies: three markers on the head (cap) , one

on each shoulder and one on the stomach (bib), one on the back (adhesive), one on each elbow (straps), one on each wrist (straps), one on each hand (adhesive), one on each knee (adhesive), and one on each foot (socks).

The spacing of our wrist markers was informed by the resolution of the OptiTrack cameras. During testing with a life-size infant doll, two reflective markers were placed directly on the wrist. The cameras repeatedly had issues distinguishing these two markers as separate entities. At this point the decision was made to construct a Velcro wrist strap that would hold the wrist markers a sufficient distance apart, allowing the cameras to distinguish the two markers.

After pilot testing the marker layout was updated by removing the markers on the back, elbows, hands, knees, and feet because of their lack of relevance toward our research goals, the interference they caused with the other markers, and the potential discomfort for our participants. At this time, foam supports for the markers on the shoulders and wrist straps were added to support and elevate the markers off of the infants' bodies for camera reception. Overall, through multiple rounds of testing and refinement, an effective marker layout was established to maximize data that could be acquired from the areas of interest and to minimize the risk of misidentification of markers.



Figure 15: Front view of final infant motion capture suit.

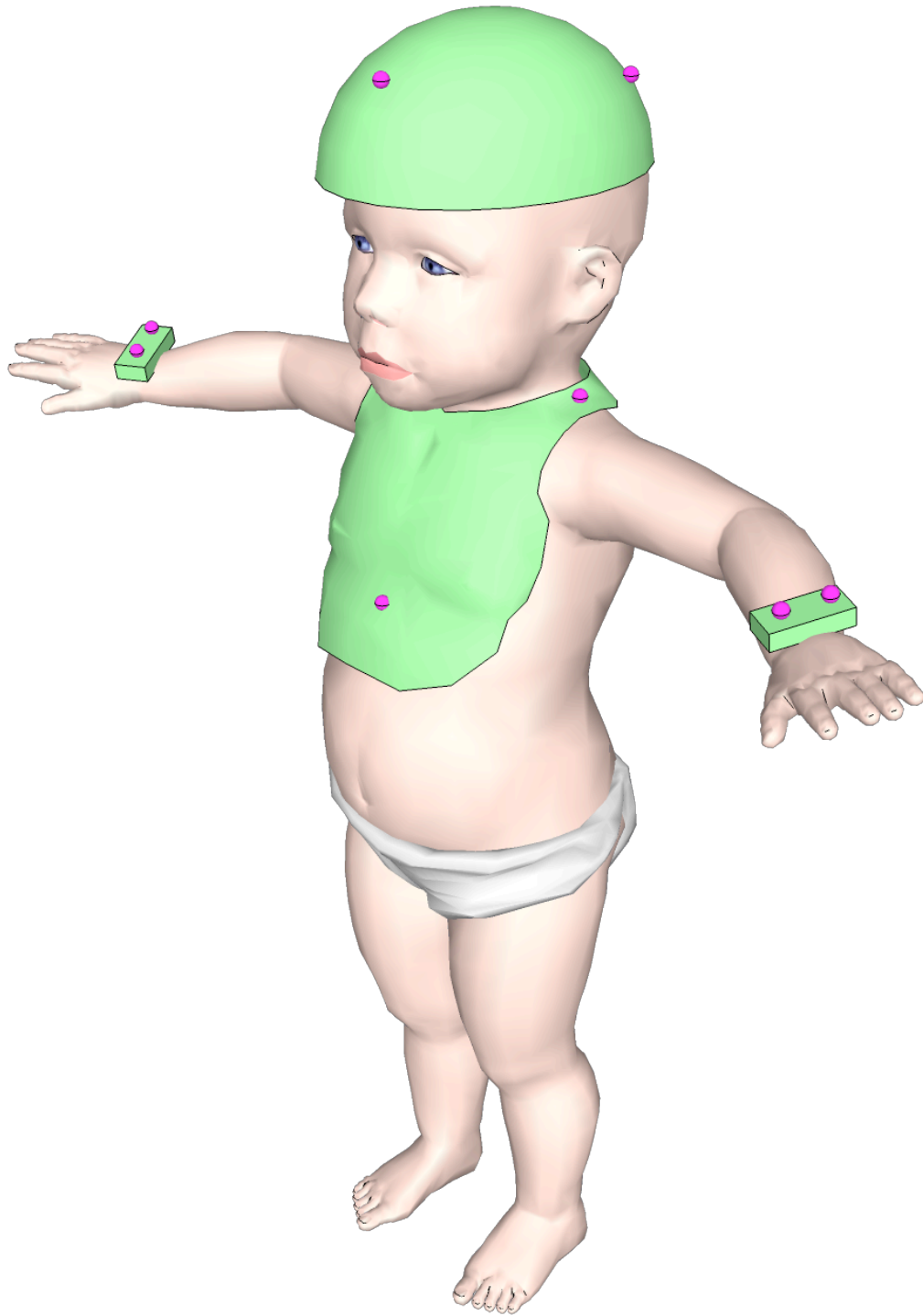


Figure 16: Side view of final infant motion capture suit.



Figure 17: Side view of final infant motion capture suit.

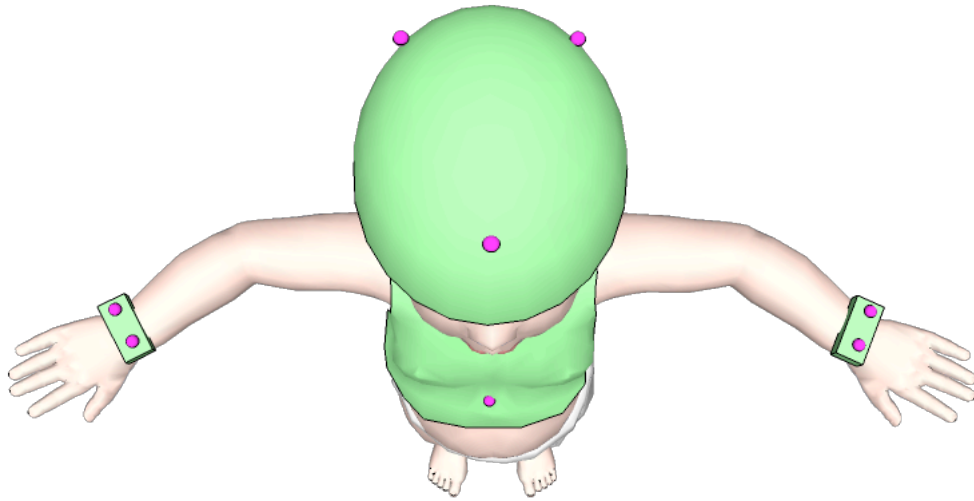


Figure 18: Top view of final infant motion capture suit.

3.4.4 Relation to indicators (Connected components)

Our team also had two low-priority goals of modularity and connected components. We created modularity by having separate pieces of the suit - bib, cap, and wrist straps - so that if one piece failed or was damaged, we could replace it without needing to replace the entire suit.

We further used modularity to our advantage by creating connected components. Three or more markers that move as a unit define a plane and create a rigid body in the Tracking Tools software. Through these rigid bodies, the position and orientation of a suit element with three reflective markers could be tracked, which was the basis of our concept of connected components. Each suit element was designed to include a single connected component of three markers, as demonstrated in Figure 19 below.

Figure 19: These pictures show the individual suit elements as connected components. Note the first element, the bib, with three reflective markers - one on each shoulder and one on the chest - which together define a plane and create a rigid body. Note the second element, the cap, with three (two visible) reflective markers - two on front side of cap and one on reverse side - which together define a plane and create a rigid body.



Through modularity we were able to determine the relevance of each of the suit's elements to each of the tasks. Even though the wrist straps did not have the three necessary reflective markers to define a plane and therefore track orientation, we treated the wrist straps, as seen in Figure 20 below, as rigid bodies in the reach-to-grasp task which only required tracking position. We could therefore use the wrist straps as rigid bodies to track the position of the wrist in this task.



Figure 20: Original Velcro wrist straps. Note the two reflective markers to track position. Foam supports stabilized and elevated reflective markers on wrists.

3.5 Recruitment and Selection

In order to test our motion capture system and setup, we sought two groups of infants – one low-risk and one high-risk. Inclusionary criteria for the control, low-risk group were simply age between six and 12 months. Six months was chosen because research indicates that the motor capabilities required for our tasks have developed by this age (Hadders-Algra, 2005; Thelen, Corbetta, Kamm, Spencer, Schneider & Zernicke, 1993). In addition, six-month-old infants would be more attentive and able to complete our tasks. Twelve months was chosen as the upper limit to create a sufficiently large enough age range for recruiting purposes, while still keeping the cohorts as young as possible.

For the experimental group, we recruited infants aged 6 to 12 months with an older sibling who had reliably been diagnosed with ASD. Ideally, we hoped for 15 participants in each proband, as this was a pilot study designed to establish potential validity of our motion capture system with infants.

Recruitment was initially conducted in the communities surrounding College Park with participants offered \$20 compensation for their time. Fliers advertising the

study (Appendix A) were placed in nearby schools, day care centers, autism support groups and pediatricians' offices. We also attempted to establish a relationship with the Children's Developmental Clinic, a weekly program on the University of Maryland campus that brings together children with disabilities and undergraduate mentors for various activities. Parents also attend educational meetings and support groups, and we presented information about our study to this community.

Throughout the recruitment process, the Center for Autism and Related Disorders (CARD) at the Kennedy Krieger Institute in Baltimore provided referrals from their network of families with children with autism. Many of these families lived closer to the institute, making commute time an inhibiting factor for participation. Our efforts around College Park also did not yield as many participants as the study required, so we decided to expand our recruitment zone to the greater Washington, D.C. and Baltimore metropolitan areas. Compensation was increased to \$50 to account for the increased distance. We continued to send flyers to doctors' offices, schools, autism centers, and day care centers, meet with relevant organizations such as Kids Enjoy Exercise Now, and collaborate with CARD.

Once individuals expressed interest in the study, they completed an approximately 20-minute-long telephone interview with a team member to screen for exclusionary criteria. The full text of the interview can be found in Appendix A. Exclusionary criteria included low birth weight (<5.5 pounds), premature birth, various genetic and developmental disorders, and several other birth complications. A full listing of exclusionary criteria can be found in Appendix A. If the potential

participant did not fulfill any of the exclusionary criteria, he or she was classified as high risk if he had an older sibling already diagnosed with ASD. Nine low-risk participants and three high-risk participants completed the study. Information about our participants can be found in Table 1.

Table 1: Participant Demographics.

Risk	Gender	Age (days)
Low	Male	223
Low	Female	245
Low	Female	259
Low	Female	280
Low	Female	314
Low	Female	322
Low	Female	338
Low	Female	353
Low	Female	364
High	Female	288
High	Female	318
High	Male	358

3.6 Protocol

The procedure for conducting motion capture sessions was standardized across the course of the study, to the extent that it could be controlled. By establishing a protocol, many potential confounding factors due to the execution of the test by different team members and the variation in the participants were minimized.

3.6.1 Researcher Roles

Four members of Team AMIRA were needed to execute the motion capture sessions assuming the roles of primary researcher, secondary researcher, observer,

and computer technician. The role of the primary researcher was to directly interact with the participant by stimulating multiple trials of each of the tasks and ensuring comfort of the infant. The role of the secondary researcher was to ensure the comfort of the participant's parents or guardians by answering questions about the study, as well as to provide assistance to the primary researcher. The role of the observer was to operate a video camera [for the sessions in which participants had consented to be videotaped] and to record on an observation sheet the timing of the tasks during the session, as well as additional motions or comments of interest. A copy of the observation sheet can be found in Appendix A. The role of the computer technician was to calibrate the system, ensure that data were being collected, and to ensure that data were being saved throughout the sessions.

3.6.2 Sanitization

All of the items that came in contact with the participants during the course of the study were sanitized before and after each session for the safety of the infants. The toys, wrist markers, and mat were wiped down with disinfecting wipes, and the bib and hat were hand-washed.

3.6.3 Calibration

The OptiTrack system needed to be calibrated prior to each motion capture session using the Arena software. First, the potential capture volume seen in the frame of any camera was cleared of reflective materials, such as running shoe reflectors and jewelry. Anything that reflected the infrared light emitted by the

cameras and could not be moved was then blocked. The camera system treats blocked points as blind spots, so that they would not be tracked. Next, the calibration wand, seen in Figure 21, was waved throughout the potential capture volume and the ARENA system would provide a calibration rating based on the depth and breadth of coverage, and the capture volume was accepted for the session depending on its calibration ratings. Calibration ratings ranged from poor to exceptional. Only the two highest camera calibration ratings, “Excellent” and “Exceptional,” were accepted for individual cameras and only the top rating, “Exceptional,” was accepted for the overall system calibration.

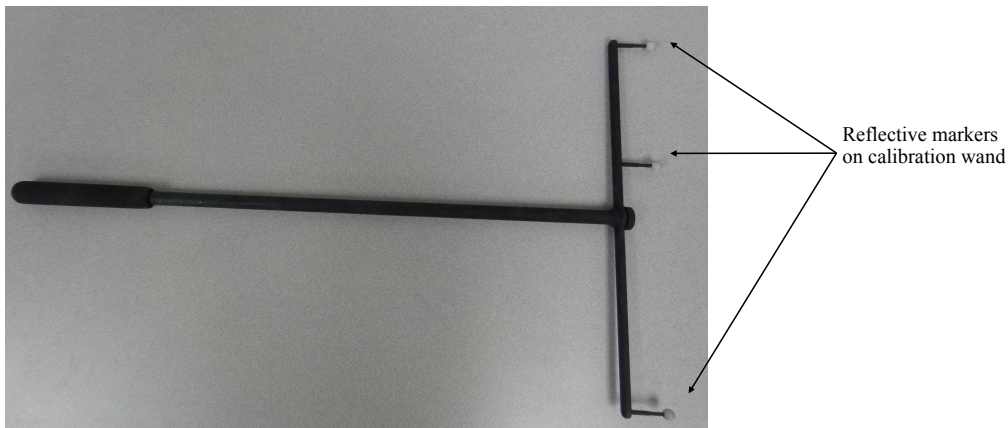


Figure 21: Calibration wand. Three markers with known spacing attached to rigid wand were used to create the capture volume.

The system calibration was completed by setting the x-, y-, and z-axes. By using a three marker triangle of known dimensions, the x- and y- axes, known as the ground plane, seen in Figure 22, was established. The z-axis was established as a normal vector to the x, y plane. The generated calibration file was then imported into

the Tracking Tools software at the beginning of the data collection session.

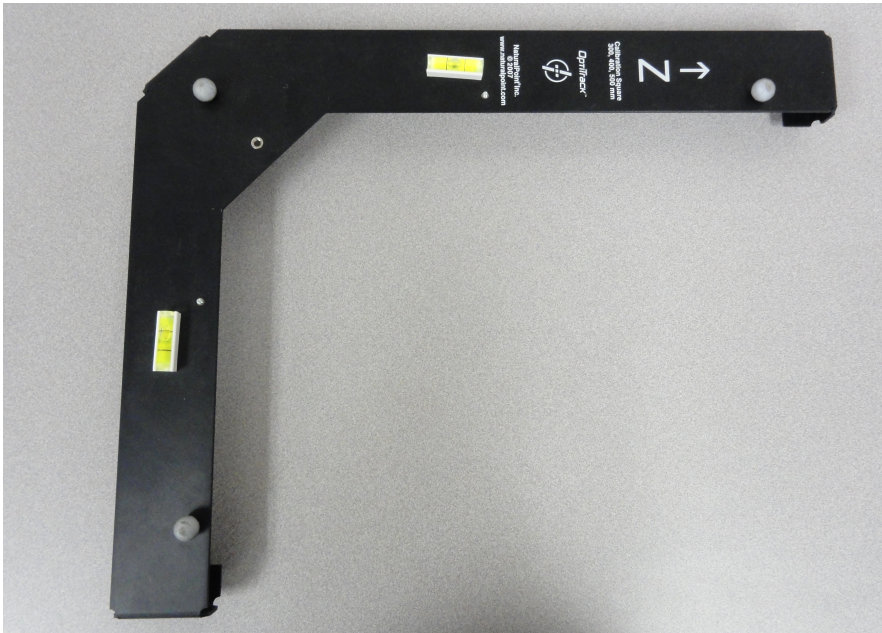


Figure 22: Ground plane, used in system calibration to establish the axes.

3.6.4 Session Protocol

The primary and secondary researchers both greeted the participant and his or her parent or guardian and brought them to the motion capture laboratory. The primary researcher then initiated interaction with the participant to build a basic level of comfort before the trials began, and the secondary researcher assisted the participant's parent or guardian in completing the research and photography/filming consent forms as well as the HIPAA Privacy Authorization form. All three of these forms can be found in Appendix A, respectively. The secondary researcher was also responsible for answering any questions of the parent's questions regarding the study.

The primary researcher then put the custom motion capture suit on the participant over his or her clothing. The primary researcher would ensure that all

elements of the suit were securely, but comfortably, fastened to the participant. The primary researcher then continued to interact with the participant before the trials began to allow the participant to become accustomed to the suit.

Following these preliminary steps, the computer technician would begin to record motion data, the observer would start the video camera, if photography/filming consent was obtained, and the primary researcher would begin the execution of the four tasks. The primary researcher would start with the pull-to-sit because this was the most unpleasant task for the infant and needed to be alternated with other, more engaging, tasks. The primary researcher then proceeded with the remaining tasks, alternating between the tasks in response to the infant's changing temperament and cooperation.

The goal for each session was to obtain motion data for three good trials of each of the four tasks. However, because of the temperamental nature of the participants and technical difficulties experienced with the OptiTrack System, it was not always possible to record the desired number of trials. The team would obtain data for as many good trials as possible for each task. To verify that a successful trial had been completed, the computer technician watched the progress of the motion capture session on the Tracking Tools user interface, which displayed the visible markers in real-time. This measure ensured that none of the necessary markers were misrepresented or occluded. Each motion capture session ran approximately 90 minutes from calibration to clean-up.

3.6.4.1 Infant Consolation

One of the most difficult aspects of working with infant participants was the factors that could influence the infant's behavior. While every effort was made to accommodate the infant without compromising the integrity of the data, the safety and comfort of the infant was the priority.

If an infant became upset during the session, the primary researcher would first attempt to comfort the infant. However, if the infant was inconsolable, the parent attending the session was allowed to step in and comfort the child. Unfortunately, parent intervention often decreased the infant's willingness to cooperate with the primary researcher and also introduced a confounding factor. If the infant would no longer perform the designated tasks with the primary researcher, the parent was asked to conduct the tasks with the infant.

3.7 Forms

3.7.1 Questionnaires

The parents or guardians of participants were asked to fill out three questionnaires, the Rothbart Infant Behavior Questionnaire (Rothbart IBQ), the Communication and Symbolic Behavior Scales Development Profile Caregiver Questionnaire (CSBS Caregiver Questionnaire), and the Communication and Symbolic Behavior Scales Development Profile Caregiver Perception Rating (CSBS Caregiver Perception). These three questionnaires can be found in Appendix A. Following the screening process, the Rothbart IBQ and the CSBS Caregiver Questionnaire were mailed to the parents or guardians of admitted research

participants. These two questionnaires were to be filled out prior to and returned on the date of the participant's motion capture session. The Rothbart IBQ and the CSBS Caregiver Questionnaire were used to collect information regarding the various developmental aspects of participating infants including: temperament, activity level, fear, and soothability. Following the completion of the motion capture session, the parent or guardian who was present at the session was then asked to fill out the CSBS Caregiver Perception, which was used to assess the infant's behavior during the motion capture session, such as whether the infant was more or less active than usual, or behaved typically.

3.7.2 Observation Forms

During each motion capture session, two separate forms were used by the team to qualitatively describe and assess the session. The first form, the Action Log, was used to denote the time of each designated action performed by the infant. The time recorded on the log was later used to help locate the start of each action in the recorded data. The Action Log can be found in Appendix A.

The second form used to evaluate the motion capture session was the observation sheet. The observation sheet used a series of Likert scales to evaluate the infant's cooperation during each task. The observation sheet relied on a series of preset questions to create a descriptive narrative of each motion capture session. For example, for the reach-to-grasp task, the form asks for what toy was used during the task, what the orientation the toy was held in, the orientation and behavior of the infant's legs while reaching for the toy, and a Likert Scale assessing the infant's

cooperation during the reach. The Likert scale used ranged from one, designating an uncooperative infant to a five, designating a fully cooperative infant. Furthermore, the Observation Sheet provided space to record any deviations from the designated protocol and comment on anything unusual or not otherwise accounted for. The full observation sheet used can be found in Appendix A.

3.8 Confounding Variables

Infant studies are, by nature, difficult to control. Each infant's disposition and tolerance for performing the tasks is different, and as a result, each test session cannot be controlled for identical conditions. An unhappy infant will act differently, and often refuse to complete the each task. Every effort was made to adhere to the predetermined protocol, but in many cases, the infant was not cooperative. In most cases, the tasks were rearranged to maximize infant engagement in order to accomplish all of the goals. Several infants were not interested in even the most engaging tasks, and the role of primary researcher was fulfilled by the mother instead of a researcher.

3.9 Data Labeling and Analysis

3.9.1 Manual Data Selection

The raw output from the TrackingTools program was a comma-separated values (CSV) file that contained all of the data from the recorded motion capture session. Each line of the CSV file represented the x,y, and z coordinates of each point being tracked by the camera system during a single frame. As each frame represented

a time period of 1/100 seconds, complete CSV files could extend for several hundred thousand lines, depending on the duration of the motion capture session.

To visualize the collected data, the team created video representations of the CSV files by sequentially plotting the data points in every frame. The frames were then converted into a MATLAB movie file using the movie function. The video files were then converted into an MPEG file, a universal video file format, using a third party MATLAB program called “mpgwrite” (Foti, 2010). The conversion to MPEG format was necessary because many computers cannot run MATLAB movie files. Computers running the Mac operating system or versions of Windows newer than Vista cannot install the software required to view MATLAB movie files. Because of the large size of the videos and the amount of computer memory required for creating the videos, each data file was divided into sets of 3000 frames. In addition to preventing MATLAB from spontaneously crashing, the reduced file size allowed us to more easily identify the designated action containing frames.

Using the action logs as a guide, the four designated actions were located within each of the data files, and the start and end frames for each action were designated. This process was performed by visually identifying the frame in which the markers began to move in the direction specified by the action of interest. To aid in selecting the start and end frames, the videos were played at approximately 3.5 percent normal speed (slowest possible was 1000 frames in 285 seconds). Despite attempts to minimize potential error in selecting the start and end frames, the margin of error was determined to be plus or minus five frames in both the start and end

frames. An error rate of plus or minus five frames in both the start and end frames, where each frame represents 1/100 seconds, lead to a 6.66 percent maximum error in a 1.5 second action. The six percent was calculated by multiplying the time of each frame, 0.01 seconds, by the maximum margin of error in labeling frames of ten. The calculated value was then divided by the total movement time of 1.5 seconds, indicating a 6.66% error. The average visual tracking action was 3.4 seconds, so the error in these actions would be approximately half as much.

3.9.2 Point Labeling Algorithm

The raw data generated by the TrackingTools program described spatial coordinates for all visible markers during an action. However, performing any analysis of the data required knowing which coordinates corresponded to which body parts on the participant. It is possible to automatically label markers with a preset skeleton. TrackingTools provides functionality to track rigid bodies such as individual body parts, but in practice this was not useful.

Our use of a custom-designed suit necessitated that we manually label the suit's markers to their corresponding body parts. To do this, the spatial coordinate points of each marker were labeled according to their location on the participant's body. An algorithm was developed to identify and label the individual markers in each frame in order to expedite this process.

3.9.3 Description of Labeling Algorithm

The first step to label the markers in all the frames of an action was for a researcher to manually label a single frame with all markers present. This frame established reference measurements for the relationship between certain points, particularly groups of points such as the three markers on the head. After the single frame was labeled, an iterative labeling procedure would assign labels to points in the rest of the frames. Strategies for labeling included labeling by proximity and modeling. Labeling by proximity is based on the assumption that markers can only move a certain distance between frames, so the closest points between two frames are probably the same marker. Modeling relies on marker positions relative to one another on the body. This procedure iterated through the data frame by frame, and labeled as many points as it could.

Using both techniques, frames were labeled in both directions because the algorithm could sometimes detect points when reading in one direction, but not in the other direction. The algorithm began with the frame following the manually labeled start frame and proceeded to the end frame of the action. The algorithm was then applied in reverse, from the end frame back to the start frame, and a final time from the start point to the manually labeled frame. This method ensured that the labeling algorithm passed over each frame twice.

The first technique for labeling points, called labeling by proximity, used the principle that points could only move a certain distance between frames. Since the time between each frame was approximately 1/100 seconds, this distance was small (2 cm). This distance threshold was determined through trial and error, selected to

maximize specificity and sensitivity. To do this, a sample video was viewed several times with different thresholds, until a threshold was found that optimized the labeling algorithm. To ensure verification, the sample video was one in which the correct labels were easily identifiable by sight.

Thus, labeling by proximity attempted to match already labeled points in the previous frame to nearby points in the current frame. If there was exactly one point in the current frame within a distance threshold close to a labeled point in the previous frame, the point in the current frame received the same label as the matched point in the previous frame.

If there was more than one point within the distance threshold from the labeled point in the previous frame, none of the points was given the label. Instead, the points would be left unlabeled for other techniques to identify. Where those also failed, the label was left unassigned.

When there were no points found within the distance threshold of a previously labeled point, the cause was often points being occluded. Occlusions occurred when a marker was seen by fewer than three cameras (usually because some part of the body was blocking it from view), and so its three-dimensional position was unable to be determined. In the event that a marker was occluded, there was no previously labeled point to use as a reference.

After proximity labeling for a frame was finished, the set of candidate points consisted of points still without labels. The remaining labels had to be assigned to

these candidate points. In these instances, the algorithm had to apply another method of labeling.

The second labeling technique, modeling, applied the constraints of a rudimentary skeleton to the remaining unlabeled points. With measurements taken from the manually labeled frame, the approximate distances and angles between the points within each rigid body were known. Since these values should have remained constant throughout an action, candidate points that did not form the expected angles or distances from the other markers within the rigid body were eliminated from the set of remaining candidate points. In order to account for small movements within rigid bodies such as shifting of clothing, percentage thresholds were applied. The percentage thresholds of some rigid bodies were higher than others, because those rigid bodies had more inherent flexibility. These threshold values are shown below

Head	Torso	Left Hand	Right Hand
20%	20%	10%	10%

in Table 2.

Table 2: Threshold values of suit rigid bodies. The head rigid body consists of the connected component created by the three markers on the cap, the torso rigid body created by the three markers on the bib, and each hand rigid body created by the two markers on each wrist strap.

If applying these restrictions for each unused label left a single candidate point, that point was labeled. If there were no possible points, or more than one possible point, then that label was left unassigned. Modeling was also used to label entire rigid bodies at once, such as the three markers on the head or two markers on the wrist. Every subset of two or three candidate points was tested against the expected configuration of an entire or part of rigid body with multiple unassigned labels. The same restrictions applied to modeling single points were also applied

here, except that the restrictions for each point in the subset were applied simultaneously. If this procedure left only a single candidate subset remaining, the unused labels were assigned to that set of points.

After applying the modeling technique, the labeling by proximity technique was applied a second time. Labeling by proximity was used again to label points for which there had been at least two points within the distance threshold but only one point remained unlabeled following the application of modeling. At the end of this process, almost all of the points in an action were labeled. Occasionally a frame would have points that could not be labeled because of lack of information. However, this was a rare event that only occurred when several points were missing from the action for many frames. This loss of information generally prevented the use of the data, as is described in Usable Data.

3.9.4 Linear interpolation

After all the data were labeled, some points were inserted into the data to make the data more complete. When a labeled point (the first endpoint) was missing for 20 frames or less and then reestablished (the second endpoint), a linear interpolation algorithm was applied and the estimated points in the interstitial frames were generated at even intervals and assigned the missing label. Because of the short period of time in between the endpoints, it was reasonable to assume the marker followed a nearly linear path in the intervening frames.

3.9.5 Motion Indicators

After points were labeled in the frames, position, orientation, and kinematics data could be found for each of the rigid bodies. Motion indicators were identified and extracted for each of the four major actions: pull-to-sit, reach-to-grasp, visual tracking, and postural control.

3.9.5.1 Reach-to-grasp

For every reach-to-grasp action, the participant could reach with either one or both hands. Seven motion indicators were collected for each hand that made a reach. Each of these indicators used the position of the hand with respect to its final position at the object. The position of each hand was defined as the center point between the two markers on each wrist. Frames in which one or both markers for a given hand were not available were given error codes. Error frames at the very beginning and end of an action were removed, and small numbers of empty frames in the middle of an action were linearly interpolated. We used seven different motion indicators to analyze this information:

- The first motion indicator for the reach-to-grasp action was the distance versus time graph. This was a graph of the distance of the reaching hand from the object with respect to time.
- The velocity versus time graph was also calculated as an indicator, and was found by taking the derivative of the distance versus time data.
- Another derivative was taken to find acceleration versus time. Examples of these graphs are shown below in Figure 23.
- Average velocity was also used as a motion indicator

- The average acceleration was taken and used as a motion indicator.
- The next indicator was a count of what we termed ‘progression units.’

Progression units were discrete divisions in the reaching task separated by the critical points, or points where the first derivative equals zero, in the distance versus time graph. The collected data were not continuous, so the critical points were found wherever the first derivative changed sign from a positive to a negative or from a negative to a positive. The result is that each division was made when the reach stopped making forward progress toward the object and started moving away from it or vice versa. Each progression unit was defined as the period between critical points.
- Lastly, we calculated movement units, which were similar to progression units. Movement units were discrete divisions in the reaching task separated by points of inflection on the distance versus time graph, or points where the acceleration equals zero. As mentioned above for progression units, the collected data were not continuous, so the inflection points were designated wherever the second derivative changed signs between two consecutive points. Movement units were only used for the reaching task because reaching required the infant to perform movement planning. Because the other actions did not involve movement planning, movement units were not an appropriate indicator for these actions. After computing the second derivative, we counted the period between points of inflection of the hand position as a single movement unit. Movement

units allow evaluation of the planning and fluidity of a movement. The more movement units, the less well-planned the movement was, as several adjustments of position and speed of the hand had to be made in order to reach the object. On the other hand, if the hand accelerates uniformly towards the object and then slows down uniformly from the halfway point until it reaches the object, the entire reach will consist of two movement units, as shown in Figure 24.

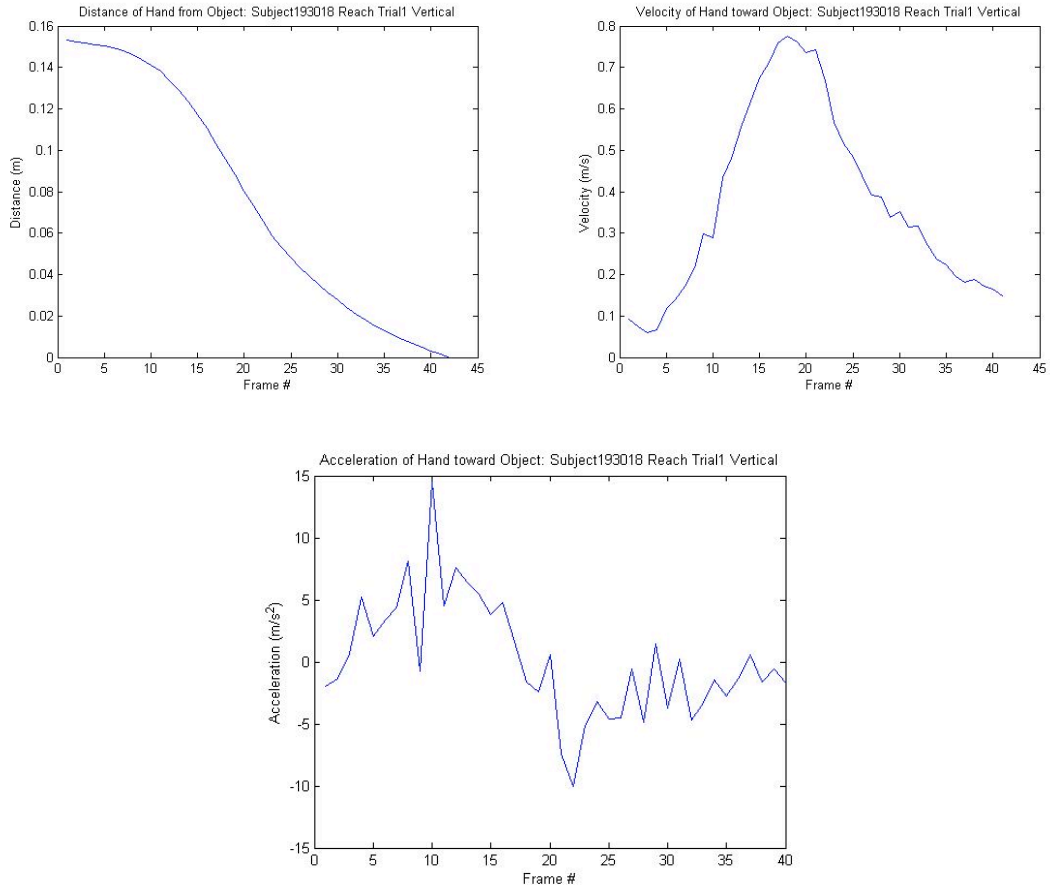


Figure 23: Example graphs of hand distance, velocity, and acceleration for a single reaching task.

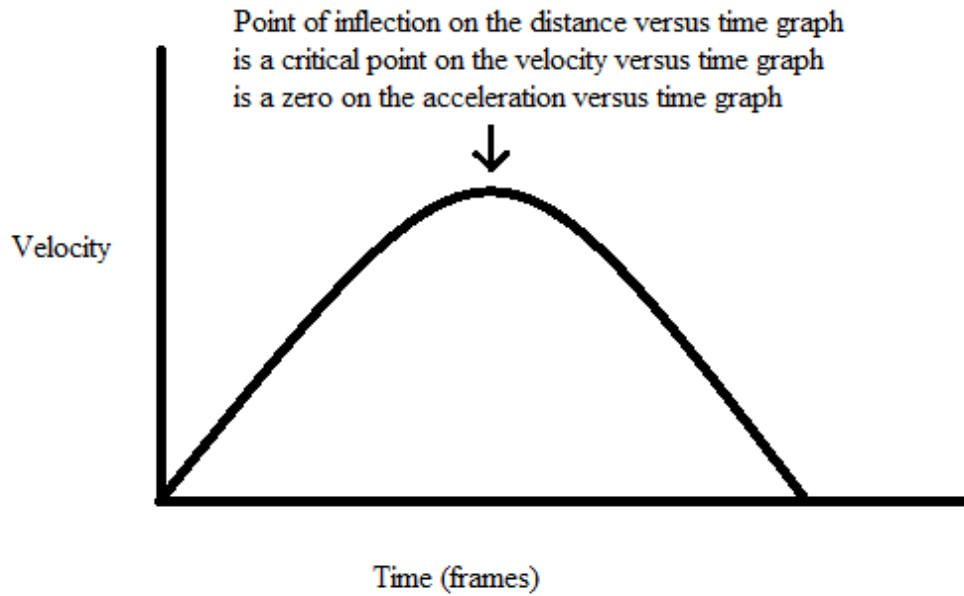
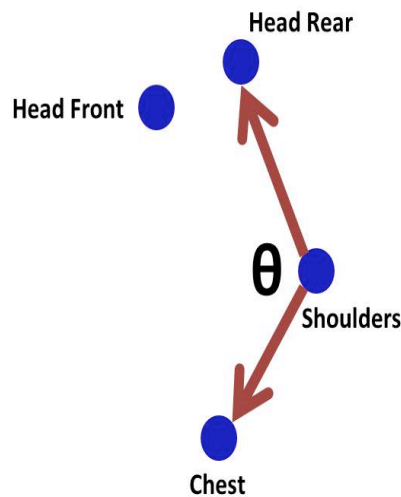


Figure 24: This velocity versus time graph has a single critical point, which is a point of inflection on the distance versus time graph, so this hypothetical reaching action consists of two movement units.

3.9.5.2 Pull-to-Sit

In each pull-to-sit action we collected six motion indicators, all of which were derived from the neck angle of the participant through the motion. The angle measured was the angle formed by the chest marker, the midpoint between the shoulder markers, and the midpoint between the rear head markers. A diagram of this angle, called the neck

angle in subsequent descriptions, is shown on the right in Figure 25. If one or more of the necessary points for computation were missing from a frame, it was assigned an error code.



Error codes were dealt with by using linear interpolation

Figure 25: Neck angle depiction, side view.

to estimate the angle. After this calculation was done, the six pull-to-sit motion indicators were computed. Those six indicators are as follows:

- The first motion indicator examined was the graph of neck angle versus time.

This indicator was a vector containing the neck angle of the participant during each frame of the pull-to-sit action. The graph of neck angle in

time typically increases during the earlier moments of the action, and eventually reaches a peak and begins to decrease for the remainder.

- The next indicator calculated was the average of the neck angle graph.
- The maximum value of neck angle was also calculated as an indicator.
- Next, the fraction through the motion at which the maximum angle occurred was observed. For example, if the maximum neck angle occurred 25 percent of the way through the pull-to-sit, this value would be 0.25.
- The next indicator was the graph representing the derivative of the neck angle versus time indicator.
- The final indicator was the maximum of the derivative graph. The average was not calculated for the derivative graph because it would be equivalent to the difference between the starting and ending angles, which was not of interest in this study.

3.9.5.3 Visual Tracking

To analyze the visual tracking task, the most important characteristic of the data was the angle between the direction of the head and that of the toy, referred to as the head angle. It is important to note that this head angle exists in 3D space, taking into account both horizontal and vertical elements of the total angle. Each of the individual indicators was derived from the head angle. To calculate the head angle, three vectors were used, as shown in Figure 26. One vector was from the back left head marker to the front head marker. We call this vector V1. The second vector, called V2, was from the back right head marker to the front head marker, so that V1

and V_2 make a “v” shape with the front head marker as the intersection of the two vectors. The third vector, M , was from the front head marker to the marker on the toy.

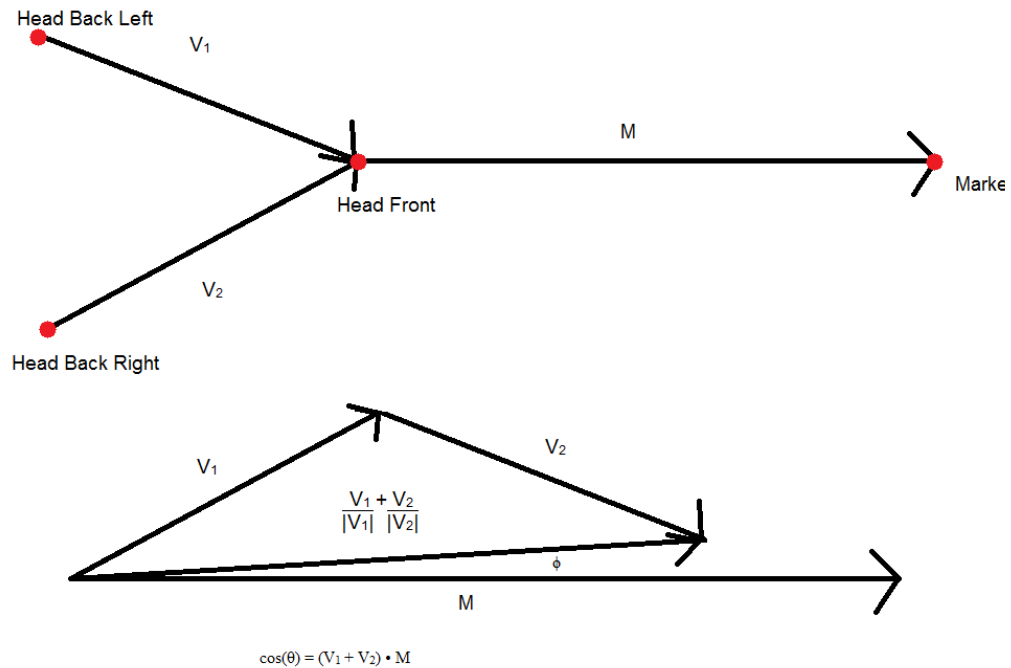


Figure 26: Head angle. Three vectors are used to determine phi, the angle between the direction of the head and the toy.

The result of adding $V_1/|V_1|$ and $V_2/|V_2|$, which each resulted in unit vectors in the directions of V_1 and V_2 respectively, was a vector in the direction of the bisector of V_1 and V_2 . The cosine of the angle between the resulting vector and M was equal to the dot product of the two vectors. The angle, phi, was then arccosine of the dot product. Phi was graphed versus time, in frames, across the entire action.

The angle between the head and the toy was used to find three different motion indicators, described below:

- The first motion indicator was a graph of the head angle data versus time.

- The second indicator was the mean head angle. Since this angle was entirely dependent of the orientation of the hat on the infant's head, an indicator independent of the average angle had to be used. Thus, the standard deviation of each frame's angle from the mean was used. This is because clinical observation suggests high-risk infants cannot follow the object across their midline. If the infant stops tracking the object at the halfway point and the angle changes dramatically, the standard deviation from the mean angle will be greater than a low-risk infant who follows the object across his or her entire body and maintains the same angle within a range of 10 to 20 degrees.
- The third motion indicator was the maximum derivative of the head angle throughout the motion. This was determined by taking the derivative of all of the angle data and finding the maximum value. The maximum derivative can also be thought of as the maximum angular velocity throughout the visual tracking test. The maximum angle was also calculated and used as a motion indicator.

3.9.5.4 Postural Control

The motion indicator for postural control was shoulder stability relative to the chest marker while the infant shook the heavy toy. If the shoulders dipped or turned relative to the chest, posture would have been deemed to be affected. However, postural control was excluded from data analysis because of frequent occlusions of

the markers, particularly the chest marker. The chest marker, along with the two shoulder markers, is essential for analysis of posture during this task. Without a reliably visible chest marker, the participant's posture could not be analyzed in any meaningful fashion.

3.9.6 Usable Data

The motion capture technology and the labeling algorithm that was used were not infallible. Therefore for each task, we had to decide which data were usable and which were not. When determining usability, the first step was to ensure that each of the actions was labeled correctly by watching the movie of the labeled action. Subsequently, each of the actions had different criteria as to what made the data usable or unusable.

3.9.6.1 Reach-to-grasp

The main criterion for determining if a reach-to-grasp was unusable was if the labels on the hands switched to other parts of the body. This occasionally happened when the hands came too close together. While the label switching could be seen in the videos of the labeled reach-to-grasp action, it could often be hard to notice, especially when it only occurred in one frame. However, the hand switching was always easily detectable during the data analysis, as it caused a large, instantaneous change in the position of the reaching hand, even if only one of the two hand markers moved. This typically manifested itself as a large spike on the distance versus time graph, and always showed up as an easily detectable large spike on the velocity

versus time graph. Because the hand-switching so drastically affected the distance versus time graph, which was important to several of the motion indicators for this action, any data where this occurred at least once were deemed unusable.

3.9.6.2 Pull-to-sit

In the analysis of the labeled pull-to-sit data, problems would sometimes occur either because of missing points or incorrectly labeled points. Both of these cases would cause an error code, which was compensated for by using linear interpolation. However, if a motion required a more than 10 percent of the total frames of linear interpolation, the data for the motion were deemed of insufficient quality, and were not used.

3.9.6.3 Visual Tracking

If any individual marker on the head or the marker on the toy was missing, the angle that was used in all of the motion indicators would be incalculable. Data were deemed usable if all three head markers and the marker on the toy were visible and labeled correctly throughout at least 99 percent of the action. Any trials with more than 1 percent of frames missing at least one marker on the head or toy were deemed unusable. Any frame missing at least one marker on the head or toy was “ignored,” that is the angle was not calculated and was given the value of the previous frame. Percent frames ignored was a statistic gathered about each trial in addition to the motion indicators in order to make this judgment. Some trials with usable data had frames excluded from the start and end because of lost markers at the beginning and

end of the action. This could not be avoided because the angle could not be calculated until all three head markers and the marker on the toy were present.

3.9.6.4 Postural Control

As addressed above, none of the postural control trials were of sufficient quality to be used in data analysis because the chest marker was occluded for a large portion of most trials. While playing with the toy, participants often moved their hand or arm in front of the chest marker, blocking it from view of the cameras. The chest marker is essential for retrieving the motion indicators for the postural control task, so the frequent occlusion rendered all the data for this task unusable.

3.9.7 *Analysis Techniques*

In order to analyze the motion indicators extracted from TrackingTools CSV files, we applied a series of mathematical tests that fall into two categories: statistical tests and vector analysis techniques. As a general rule, any motion indicator that was a single value, such average velocity or number of movement units, was analyzed using statistical tests. On the other hand, any motion indicator that was a vector or a graph, such as angle versus time, was analyzed using vector techniques.

3.9.7.1 Statistical Tests

The purpose of the statistical tests was to allow for aspects of different populations to be compared with a defined degree of confidence. There were many statistical tests to choose from, and each was designed to work on data in different circumstances and for various purposes, with several advantages and disadvantages.

Because of the nature of the experimental set up, both the F -test and Welch's t -test were used to determine differences between the high- and low-risk populations. The two tests were applied together on the data and were both necessary because of the probabilistic nature of statistical testing. When a large number of t -tests are used on the same data set, probability indicates that a subset of the tests may randomly produce false-positives. Therefore the F -test was used to differentiate true positives from false positives by ascertaining if the two conditions differed in general. Of course, the F -test is also capable of false-positives, but these are less likely because fewer F -tests are used to analyze the data.

After the single-value motion indicators were measured for each action, the F -test was used to determine the size of the main effect between the high- and low-risk conditions. The main effect was a measure of how much the two subjects differed from one another on all motion indicators taken from a single task. The greater the main effect, the more the conditions differed overall, and the more statistically significant the F -test result would be. If the F -test resulted in a significant p -value, further analysis was conducted by applying Welch's t -test. However, if the F -test did not result in a significant p -value, it would be mean that the conditions did not differ enough for conclusions to be drawn from that motion indicator. Therefore, when the F -test was not significant, it was not necessary to continue to Welch's t -test.

If the main effect was significant, each motion indicator for each action was then compared across high- and low-risk conditions using Welch's t -test, which estimates the probability that two groups have the same mean when those two groups

have different variances. Welch's *t*-test was chosen over the more common Student's *t*-test because it could not be assumed that the high- and low-risk populations had the same variance in their movement patterns. The variance was assumed to differ between the populations because the literature shows that ASD manifests in the two populations at different rates. Thus, Welch's *t*-test was ideal for this study.

Since there were multiple trials for each participant, and because the number of trials having sufficient quality was different between participants, the data were analyzed by this *F*-test/Welch's *t*-test process in two different ways. The first method was to analyze each trial as an independent data point. This method accurately reflected the breadth of the data collected, but was subject to relatively high bias. In other words, since each trial was treated as independent, participants who performed a larger number of usable trials influenced the data more strongly than participants who performed fewer usable trials. Essentially, this method artificially weighted the data in favor of some participants over others.

Because of this problem, a second method was also used to analyze the data. This method treated each participant as a single data point, with the statistical tests taking the mean of the motion indicators in all trials performed by the participant. This method reduced potential for bias, but also artificially reduced statistical power by lowering the sample size and eliminating much of the complexity of the data, thus rendering the study less likely to identify any differences that might have existed between the populations.

Statistical outliers were not excluded from the data because of the small sample sizes used in the research, and because of a lack of theoretical justification for excluding outliers. If outliers exist in the non-ASD population, the high- and low-risk groups should theoretically be more difficult to separate from one another.

3.9.7.2 Principal Component Analysis

The second category of tests used in this study was vector analysis techniques. Primarily, principal component analysis (PCA) was selected and used for the analysis of motion indicators that were vectors, or graphs.

The purpose of PCA is to reduce the dimensionality of a vector; this means that it breaks a vector down into a small number of components that represent pieces of the original vector. PCA can be described as a dimensionality reduction technique, meaning that it reduces its input - a vector - to an output with less complexity - a few values. These values represent the contribution of each component vector to the whole input vector and can be used to make statements such as, “The first three components represent 70% of the data.”

For this study, PCA was used to express large vectors such as neck angle versus time on a redefined axis as a point in a three-dimensional coordinate system. A single point was generated from each participant action trial using this method. If the group of points from one of the participant populations was distinctly separate from the other, Welch’s *t*-test was used to distinguish them. PCA was important here because statistical methods, such as Welch’s *t*-test, do not work on complex data such as

vectors. Only after PCA has been applied to reduce the complexity of the data do they become useful.

This process was applied to every motion indicator that was a vector. It was also applied to an artificial vector for each task, which was created by concatenating the single-value motion indicators together into a vector. For example, the artificial vector for pull-to-sit was the average neck angle, maximum neck angle, maximum neck angle location, and maximum derivative values concatenated together. This artificial vector was created because it allowed the single value indicators to be analyzed simultaneously, compared to the statistical tests which analyzed them separately.

We used MATLAB's "princomp" function to compute a variety of scores associated with PCA. The first output of the function was the coefficient matrix of

the principal component, which are the projections of variables into the principal component space. The function then displayed the principal component scores for each data entry that were input. These scores represented the components of the projection of the participant trials into the computed principal component space, and could be visualized with

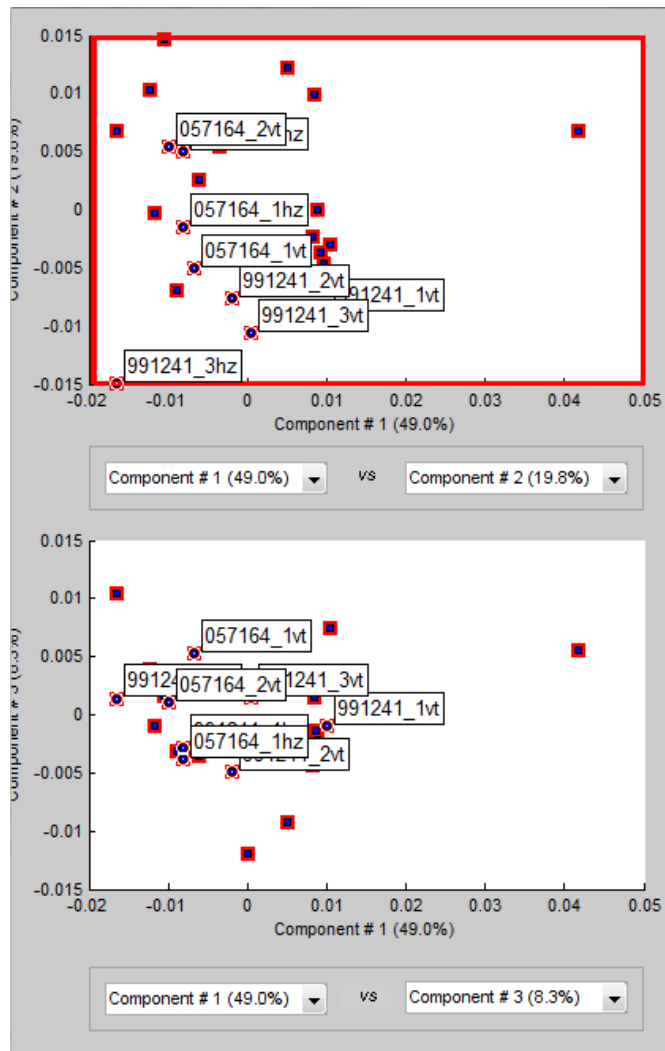


Figure 27: Example output of MATLAB “mapcaplot” tool used for initial data visualization.

utility, as per Figure 27. The third output created an array

that contained the eigenvalues of the covariance, which were used to calculate the percent of the data that is represented in the principal component. These numbers were cumulative and as more principal components were considered, the value of the array came closer to one. A value of one meant that all of the data were represented by that component. The next output was another array of values that corresponded to

the latent value of the principal component. The latent value represented the eigenvalues of the covariance matrix that was made from the originally loaded matrix of task data. This value also represented the variance of the scores of the principal components. Finally, the last output of the princomp represented Hotelling's T2 statistic for each data point. These T2 values were the computed distance of each participant trial to the center of the data set.

If a participant's trial contained more frames than another, it would generate longer vectors for its motion indicators. This would have been a problem, except the functions used in MATLAB already accounted for vectors of different lengths. In order to normalize each trial, MATLAB subtracted the mean of each respective trial from each vector. This way, all trials could be directly compared.

Chapter 4: Results

The analysis techniques explained above were applied to each participant and trial recorded during this study. The results of that process are described here. The reach-to-grasp, pull-to-sit, and visual tracking tasks yielded usable data. However, only reach-to-grasp contained significant results.

4.1 Statistical Tests

4.1.1 Reach-To-Grasp

The reach-to-grasp task yielded usable data from 23 trials, consisting of 9 high-risk and 14 low-risk. An F -test confirmed the existence of a main effect on the data because of the data from high- and low-risk conditions ($p < .001$). Because a significant main effect was found, further analysis was conducted to compare each motion indicator across conditions using a Welch's t -test. Four such tests yielded statistically significant results.

First, the average velocity indicator for the left hand during the horizontal reach was found to differ across conditions, as shown in Figure 28 ($p = 0.040^{**}$). The average velocity was significantly lower in the high-risk population. Similar results were found for the right hand during the horizontal reach ($p = 0.027^{**}$) and the right hand during the vertical reach, as shown in Figure 28 ($p = 0.002^{**}$). Second, the number of movement units for the right hand during the vertical reach was found to differ significantly across conditions, also shown in Figure 29.

Score distributions of Significant Reach Velocity Indicators

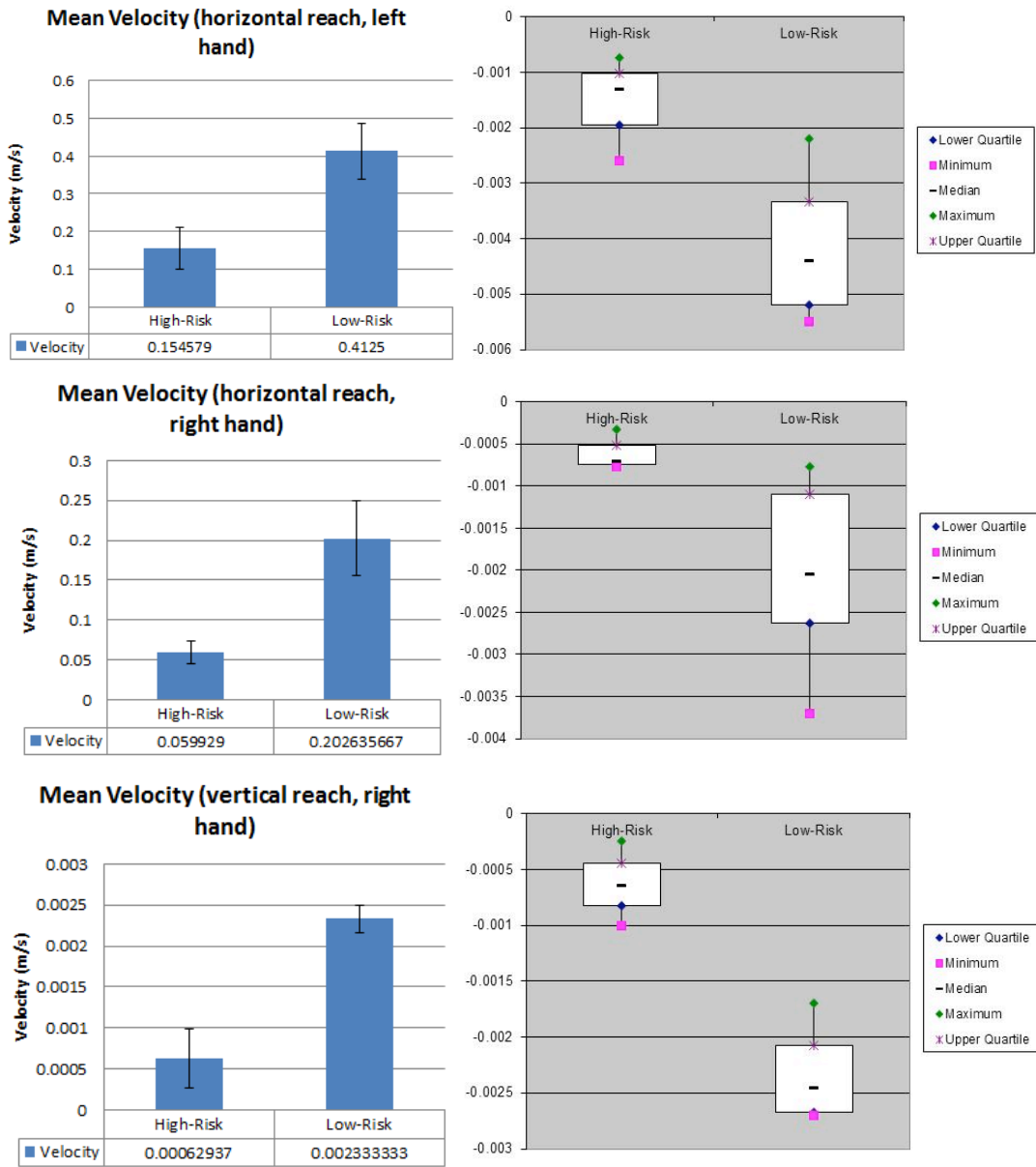


Figure 28: Significant results of mean velocity indicator from reach-to-grasp task. Left: Mean scores with error bars. Right: Detailed score distributions.

($p = 0.043^{**}$). High-risk participants demonstrated a significantly greater number of movement units than low-risk participants demonstrated in this task. However, since this difference only appeared for the right hand during the vertical reach, the validity

of this result is questionable. The following motion indicators did not differ significantly during the horizontal reach: average acceleration of the left hand ($p = 0.161$), movement units of the left hand ($p = 0.208$), average acceleration of the right

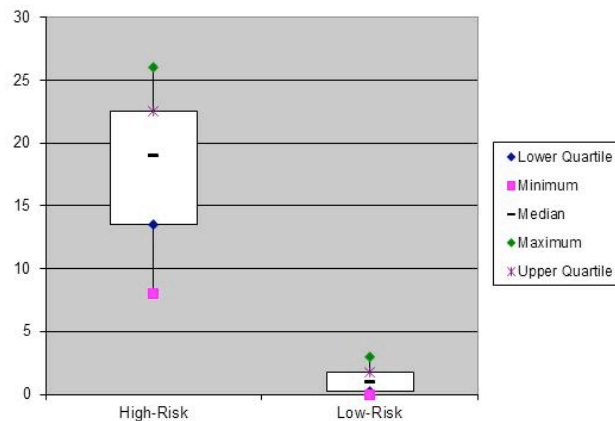
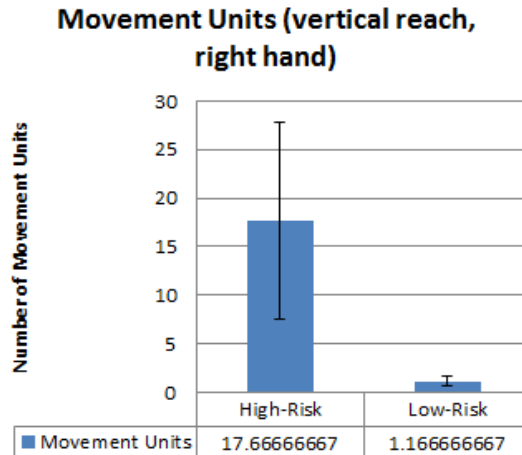


Figure 29: Significant result of movement units indicator from reach-to-grasp task. Top: Mean scores with error bars. Bottom: Detailed score distributions.

hand ($p = 0.801$), and movement units of the right hand ($p = 0.131$). The following indicators did not differ significantly during the vertical reach: average velocity of the left hand ($p = 0.174$), average acceleration of the left hand ($p = 0.241$), movement

units of the left hand ($p = 0.086$), and average acceleration of the right hand ($p = 0.115$; Figure 30).

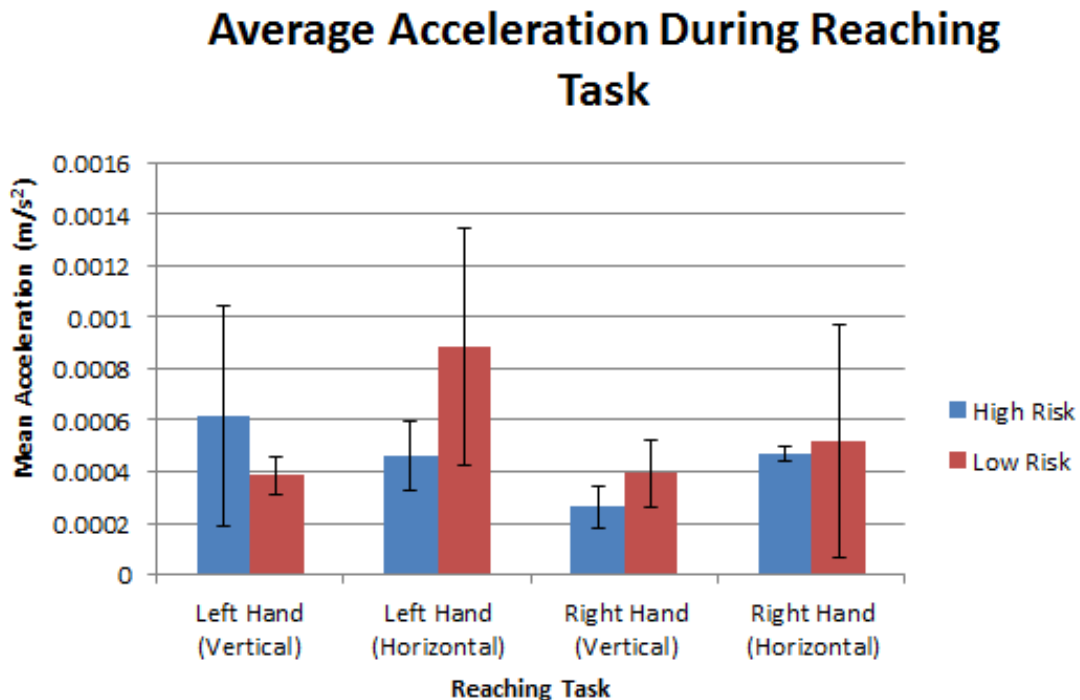


Figure 30: Non-significant results of mean acceleration indicator from reach-to-grasp task

The reach-to-grasp task results were attained by analyzing each task as a separate data point. The method of analysis accurately portrays the breadth of the data, but increases potential bias because of individual participants who performed a high percentage of usable actions. In an attempt to offset this bias, the data were also analyzed by averaging the motion indicators for each participant and then treating each participant as a separate data point. The usable actions represented 6 participants (2 high-risk, 4 low-risk). An F -test was performed on the data, demonstrating a significant main effect ($p = 0.049^{**}$). However, t -tests did not indicate significant differences between individual motion indicators.

4.1.2 Pull-To-Sit

The pull-to-sit task yielded usable data from 11 trials, two of which were high risk and nine of which were low risk. An F -test was performed to determine the existence of a main effect on the data, incorporating all of the individual motion indicators. However, the test did not indicate a significant main effect ($p = 0.591$). Because the F -test failed to find a significant main effect, further analysis of the motion indicators would be meaningless, and analysis of the individual motion indicators was not performed.

4.1.3 Visual Tracking

The standard deviation of the angle between the head and the toy was compared between the low-risk and high-risk trials with Welch's t -test. This test yielded insignificant results, with a p -value greater than 0.2. Several visual tracking trials with high-risk participants were unusable for multiple reasons, including lack of cooperation and occlusions.

4.1.4 Postural Control

There were no quantitative results for the postural control task.

4.2 Principal Component Analysis

4.2.1 Reach-To-Grasp

The reach-to-grasp task had the most usable data of the actions in the experiment, with nine usable high-risk samples and 16 low-risk samples in total. For each trial, there were four indicators computed on each hand. We calculated principal

component scores for two different vectors. One vector consisted of the concatenation of all of the motion indicators computed for each hand: average velocity, average acceleration, number of progression units and number of motion units. As we were interested in studying the motion of the reaching behavior in high versus low risk infants, we also computed principal components for a second vector consisting of the concatenation of the hand velocities at each captured frame. These vectors were 130 elements long, the length of the trial. In all cases, statistical analysis was performed on the individual components independently and qualitative analysis of the difference in distribution of principal component scores was performed using graphs and visualization tools in MATLAB.

Visualization of the combined velocity over time vector showed a clear grouping in the principal component space, which led us to perform statistical analysis on velocity and acceleration data using Welch's *t*-test. Points corresponding to trials of high-risk participants tended to be grouped together, possibly because of the tendency of infants with developmental disabilities to have stereotyped movements. We found that, in the space of the first principal component, which accounted for 43.7% of the variation between movements, there was a *p*-value of 0.095. While this is not quite statistically significant, it does suggest a possible difference in performance on the reaches. Performing the same analysis in the space of the second principal component, which accounted for 17.7% of the variation between movements, yielded much stronger results, with $p = 0.011^{**}$. Figure 31 shows the distribution of high and low participants in the first and second principal

components; this shows that high-risk trials tended to be grouped together in the space of the first two principal components, having lower scores in the second component, whereas low-risk trials were more spread out and had higher scores in the second component.

Reaching Velocity Vector Principal Component Scores

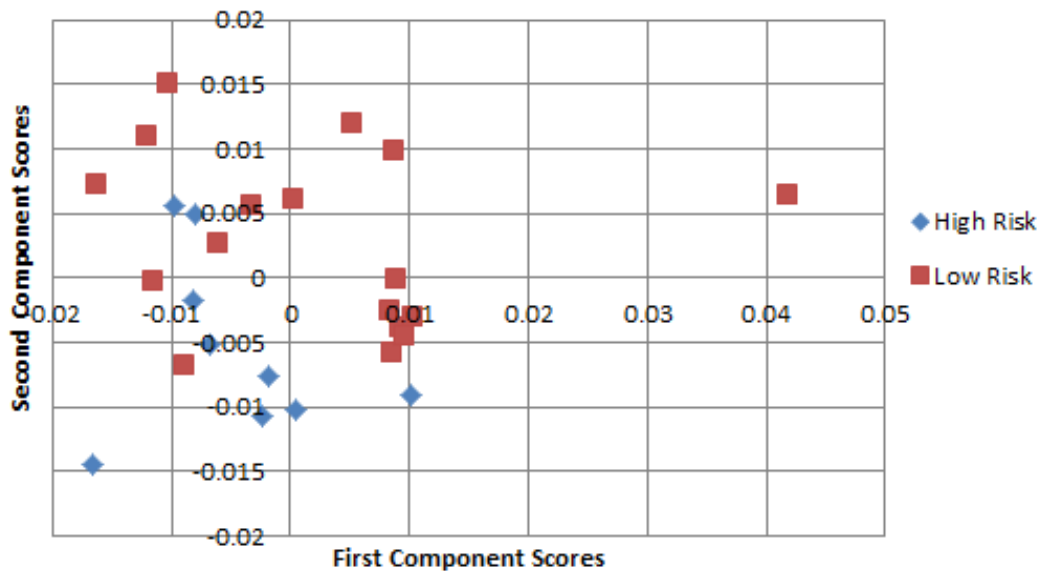


Figure 31: Distribution of high- and low- risk trials when major principal component scores are used to project them into a 2-D space. High-risk subjects show a clear trend in the second component.

When we combined all motion indicators from the right and left hands during the trial, we found more interesting results that reinforce the difference between high and low infants in the reaching task. In the first component, we again found no significant results, but Welch’s *t*-test gave us a fairly low p-value ($p = 0.169$). This may be due to the high standard deviation between trials in each component; additional research may be able to improve these results. The results in the second component were clearly significant ($p = 0.002^{**}$). Together, these two components

Representation of Motion Indicators in First and Second Principal Components

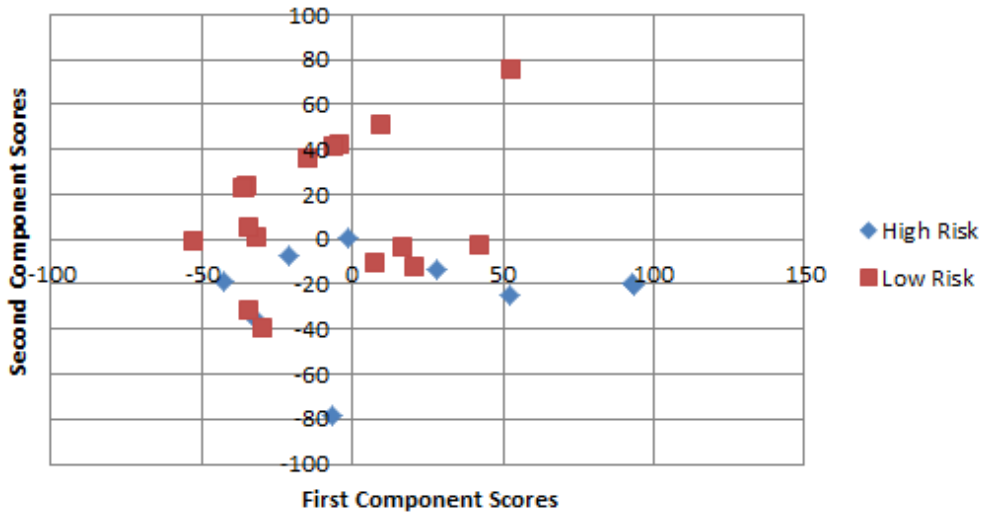


Figure 32: Distribution of trials when principal component scores are used to visualize them projected into a 2-D space; differences in 2nd component (y-axis) are clear.

Average Value of Principle Component Scores using Multiple Motion Indicators

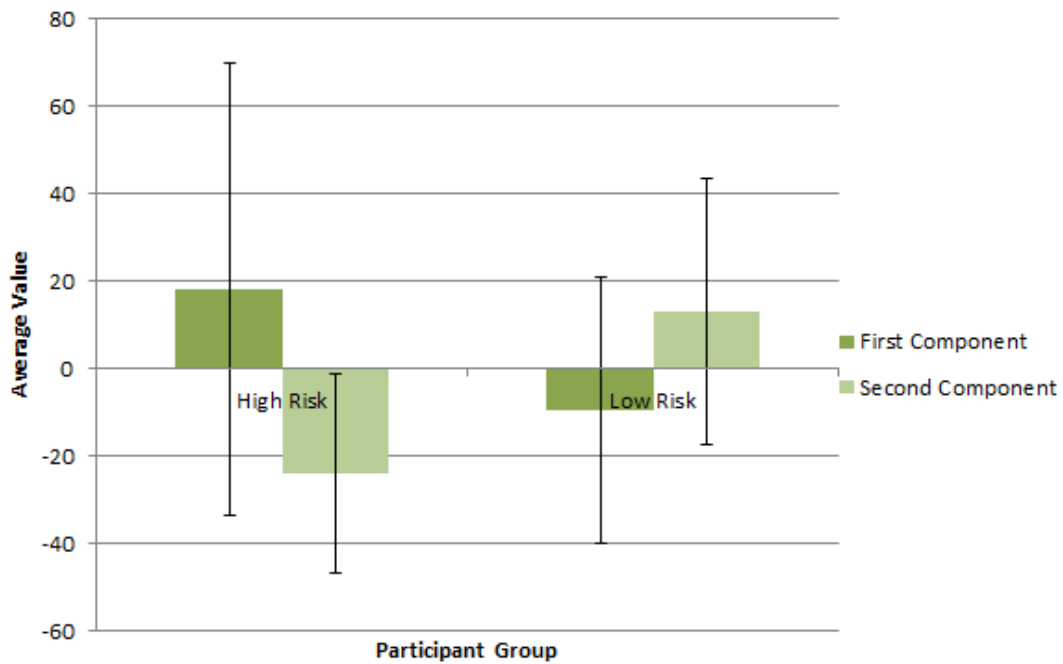


Figure 33: Means and standard deviations for principal component scores computed from multiple motion indicators; these represent 99.1% of sample variance.

represent 99.1% of the variance between these data. In Figure 32, differences between high- and low-risk participants in the first and second components can be clearly observed; particularly, high-risk participants have lower values in the second component (along the y-axis). Figure 33 shows the mean and standard deviations for these results. Because of the high spread of results in these first two components, standard deviation is still fairly high.

4.2.2 Pull-To-Sit

For the pull-to-sit action, usable data were collected from nine trials over six low-risk participants and two over high-risk participants. Three different vectors were analyzed from each participant trial. The first was the neck angle versus time indicator, the second was the derivative indicator of the first, and the last was an artificial vector containing the concatenation of the average angle, maximum angle, maximum angle location, and maximum derivative. Analysis of pull-to-sit data produced statistically insignificant results across all three indicators, as computed by the *t*-test.

When mapped into a principal component space, the angle versus time vector showed that the high-risk trials appeared to be mapped near each other in the second and third components. We performed the *t*-test on the first three principal components for each trial, with no significant results. In the first component, accounting for 53.1% of the variance between samples, points did not subjectively appear to be grouped at all. Results showed almost no chance that samples had different population means ($p = 0.970$). The second component accounted for 18.1%

of the variance, but was also inconclusive ($p = 0.318$). Means for each component varied wildly, as can be observed in Figure 34. The third, and most promising, component only accounted for 11.4% of the variance between trials, and still did not meet our standards for statistical significance for difference between trials ($p = 0.107$). We used these scores to visualize trials projected into a 2-D space; as can be seen in Figure 35, there is still no clear pattern of results.

Average Values of Principal Component Scores for Head Angle Vectors

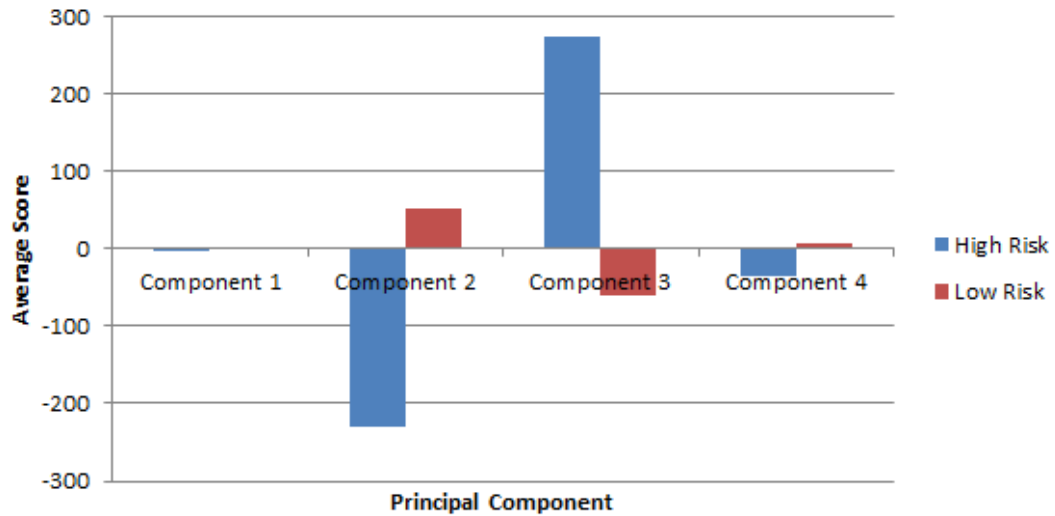


Figure 34: Shows mean values for the first four principal component scores computed from vector of head angles over time.

Head Angle Principal Component Scores

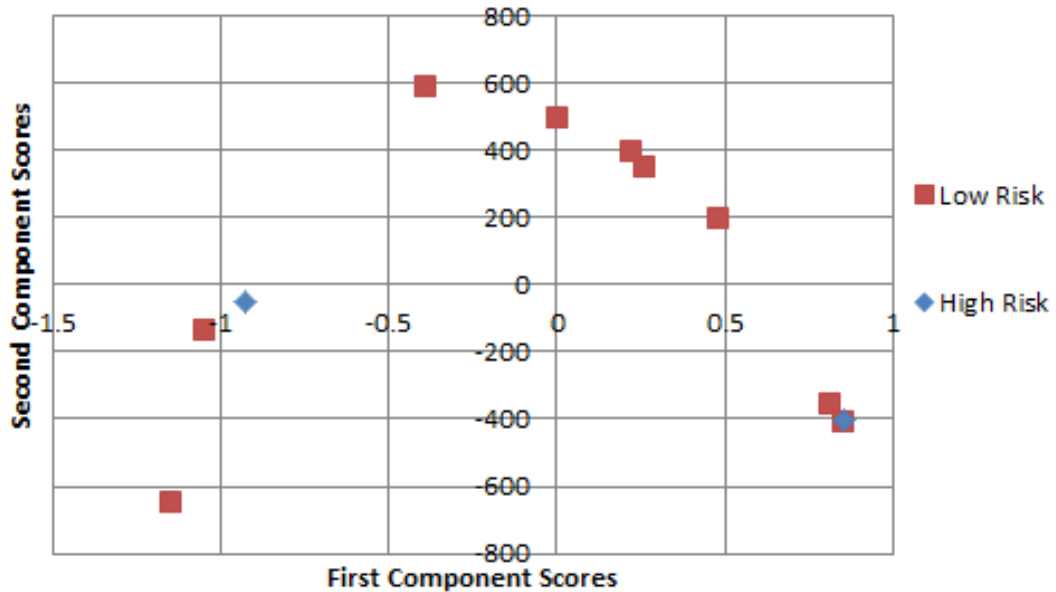


Figure 35: First and second principal component scores used to project head angle over time vectors into a 2-D space to visualize data. This shows no clear pattern.

The second indicator, derivative of head angle over time, was inconclusive as well. Analysis of the graph in Figure 36 shows some differences in the first principal component accounting for far more variance (35.4%), but using principal component scores to project trials into a 2-D space as in Figure 37 showed no clear pattern at all. However, Welch's t-test does not support this ($p = 0.280$). In fact, none of the first four components in this indicator, which together represented 85.5% of the variance in the sample, had a p-value less than 0.20. We cannot say there is any apparent difference in movement, especially since the range of PCA scores is very diverse; standard deviation between different low risk samples was many times the mean score.

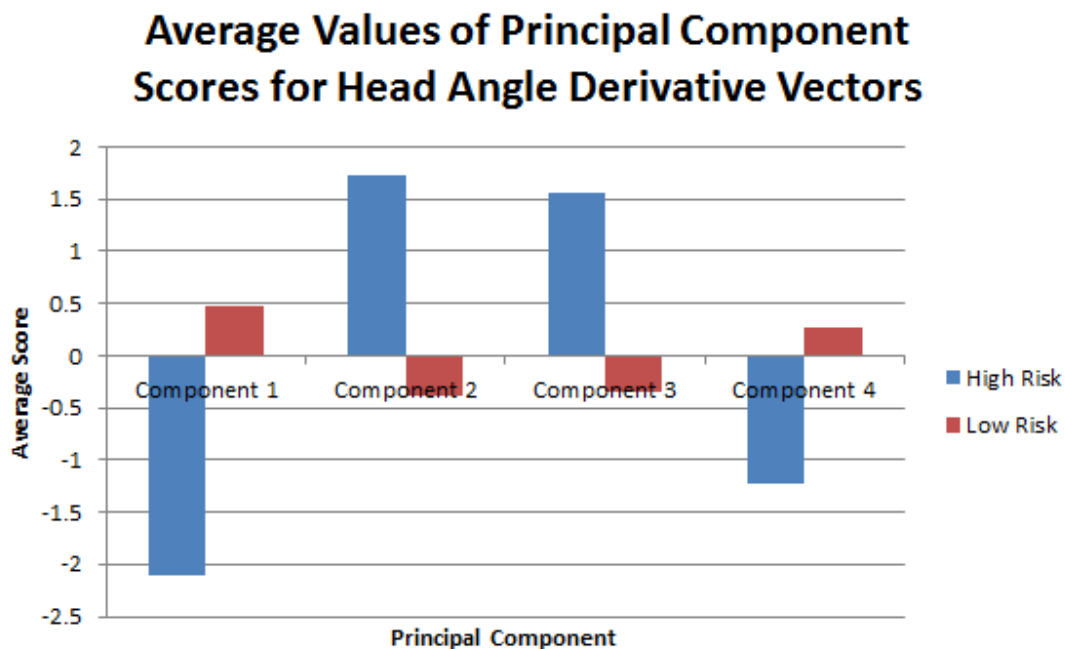


Figure 36: Shows mean values for the first four principal component scores computed from vector of head angle derivatives over time.

Head Angle Derivative Principal Component Scores

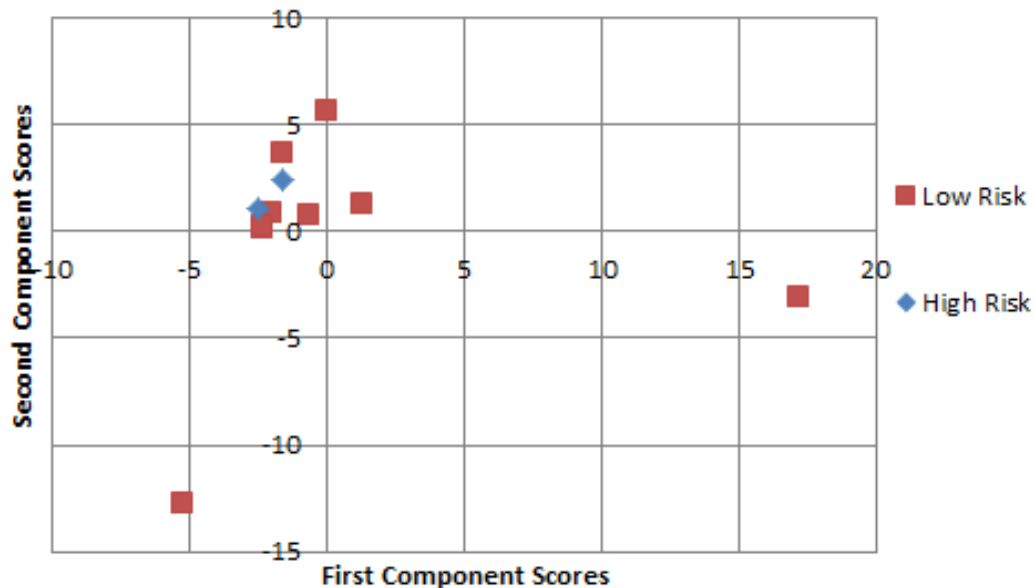


Figure 37: First and second principal component scores used to project head angle derivative vectors into a 2-D space to visualize data. This shows no clear pattern.

The last vector, composed of the concatenation of average velocity, maximum angle, and maximum angle location, also did not yield statistically significant results. Variation was almost entirely expressed in the first component (96.3%). There were no significant differences in the first component ($p = 0.715$), and standard deviations were extremely high-- for the low risk participants, standard deviation was ten times the mean score. With this information and the fact that the F-test statistic previously computed indicated no reason for further analysis of this data set, we believe that there were no major differences across this data.

It should be noted that because of issues with data collection such as occluded markers, far less information was available for the pull-to-sit task's high-risk group than for the same group in the reach-to-grasp task.

4.2.3 Visual Tacking

Unfortunately, while usable data were recorded for many low-risk participants, only one trial from the high-risk population was usable. Because PCA relies on the spatial clustering of points, one trial of high risk visual tracking data did not yield enough information to conduct this test.

4.2.4 Postural Control

There were no quantitative results for the postural control task.

Chapter 5: Title of Chapter 5

5.1 Conclusions

5.1.1 Introduction

Of the four actions, only the reach-to-grasp showed statistically significant differences between the two groups. In the pull-to-sit and visual tracking task, statistical tests did not yield results of significance. Analysis of principal components of the data did not demonstrate any significant trends for any of the data. Finally, postural control data was deemed unusable, and therefore results could not yield any significant conclusions. This section expands on these quantitative findings, while also discussing qualitative conclusions from each task.

System viability and implications of the custom suit design and infant motion captures system are also discussed. The sections ends with limitations of the study - most notably, the small sample size - and points to ways to expand on this research.

5.1.2 Tasks

5.1.2.1 Reach-to-grasp

5.1.2.1.1 Reach-to-grasp: Quantitative Conclusions and Modifications

The reach-to-grasp task exhibited a significant trend in the overall analysis of the data. The statistical analysis indicated that the significant difference from the F test of the data sets came primarily from the average velocity indicators (left hand horizontal reach and right hand horizontal and vertical reaches). The high-risk group

performed the reach-to-grasp task with significantly slower average velocities than the low-risk control group. Even though only three of the four mean velocity indicators differed significantly across the conditions, it is reasonable to assume that the fourth mean velocity indicator may differ also, and that the non-significant results were due to type 2 error. This possibility should be explored in future research.

The analysis also suggested that the movement units indicator contributed to this statistically significant difference between the high- and low-risk groups. The high-risk group displayed an increased number of movement units as compared to the low-risk group, implying that high-risk infants may have made less “smooth” movements than low-risk infants. However, only one of the cases (right hand vertical reach) exhibited the significant difference, so this result requires further validation.

PCA revealed similar results, showing that there was a significant difference between high- and low-risk groups in the second principal component, which represented 19.8% of the variation between trials. However, statistical analysis of the first component was unable to find any significant differences.

The results of this study indicated that a slower average velocity of the reach-to-grasp task is the most effective of the tested infant motion indicators for elevated autism risk. The increased number of movement units in the reach-to-grasp task for the high-risk condition implied that movement units may also be an effective indicator, but this result requires further validation.

The statistically significant results in three of the four parameters of velocity investigated during the reach-to-grasp task merited an investigation of the literature

for possible explanations. In a study of the reach-to-grasp action completed by Mari and colleagues (2003), researchers found that the low-functioning autism group, aged 9 to 13 years, had longer movement durations, decreased peak velocity, and increased deceleration time. Lower mean velocities in our results suggest that this phenomenon may exist in high risk populations at 6 to 12 months of age.

Another study by Rinehart and colleagues (2006) demonstrated that a high-functioning autism (HFA) population, ages 5 to 11 years, spent greater time in decelerative and terminal guidance phase for expected movements. The Rinehart study notes that this result is consistent with Mari and colleagues' (2003) supposition that the HFA group may be unable to efficiently modulate their movement once an action has begun. While only one of our parameters related to movement units during the reach-to-grasp task yielded statistically significant results, that trial with high-risk infants using more movement units to reach fits in with Mari and colleagues' (2003) suggestion. If an infant cannot efficiently modulate their movement during an action, it is possible that infants will not correct their course of action properly, by way of over- or under-compensating. An infant's inability to correct her reach trajectory would lead to an increase in movement units.

5.1.2.1.2 Reach-to-grasp: Qualitative Conclusions and Modifications

Although the reach-to-grasp task yielded the most robust quantitative data, qualitative reflection highlights many difficulties in infant comfort and standardization that could be modified. Infants often did not want to reach for the designated toy, leading our team to sometimes use similarly shaped objects of greater

interest to the participant, such as a pen. In a few trials, the parents needed to present the toy to the child in order for her to participate. Infants did not complete the task, especially when in a supine position prior to the reach. These observations would be considered in any modifications made to more rigidly standardize the task.

Two specific aspects of the task that would be better constrained are the starting point for the reach and the hand orientation during the grasp. Both were difficult to measure given our current system, but could be improved through the placement of additional markers on the elbow and hand. An elbow marker would create a rigid body for the forearm, allowing researchers to measure arm movement even if the hand remains in place. By tracking an elbow and chest marker, one could better measure the arm's orientation and position at the beginning of the reach. An additional marker on the infant's hand would correct for differences in hand orientation during the grasp portion of the task.

Finally, adding markers to the object would aid in the analysis of Tracking Tools' data because the researchers could more accurately determine when the infant initiated and completed the grasp.

5.1.2.2 Pull-to-sit

5.1.2.2.1 Pull-to-sit: Quantitative Conclusions and Modifications

The F-test on the combined motion indicators for pull-to-sit did not show the existence of a main effect, meaning that there was no significant difference between

the high- and low-risk populations. From this, we cannot conclude that head lag in a pull-to-sit action is connected to autism.

In PCA, neck angle versus time and derivative of neck angle vectors produced results that did not show a distinct difference between the two populations. The plot of the component coefficients showed the participant trials from each group mixed together, with no clear separation. This could have happened either because of the limited number of trials present to begin with, or because of errors with the underlying data set such as oclusions. PCA seemed to indicate that the two usable high-risk trials were closely related in space; due to the low number of successful pull-to-sit trials for high-risk participants, it may have been that we had insignificant statistical power to identify the differences.

5.1.2.2.2 Pull-to-sit: Qualitative Conclusions and Modifications

Similar to the reach-to-grasp action, the pull-to-sit was hampered by difficulties in infant cooperation and precise replication. The pull-to-sit task caused the most trouble for the participants because the infants did not want to be placed on their backs, and doing so often made them upset. However, unlike the study's other tasks, the pull-to-sit could be accomplished without the infant's full cooperation. Unfortunately, upsetting the participant during the pull-to-sit decreased his willingness to participate in subsequent tasks.

As described in the methodology, it was important for the primary researcher to establish eye contact with the infant before pulling her from the supine to seated position. This eye contact was necessary so that the infant could anticipate being

pulled up from the mat and make the necessary postural adjustments to prevent head lag, if possible. However, researchers had difficulty initiating eye contact with the infants while performing the pull-to-sit. Another confounding variable in the task was that often, some infants inadvertently slid along the surface of the mat while being pulled up. This lengthened the time for the task to be completed and affected the labeling of the start and end of the task, which were important to analysis and already difficult to determine. The end of the movement proved especially difficult, as we were unable to precisely determine when the researcher stopped pulling on the infant or when the infant reached a 90° angle with the mat.

Based on these qualitative conclusions, several modifications are posed below. First, a non-slip surface would prevent the infant from sliding across the mat and allow for more accurate data collection. Second, as the neck angle was calculated by comparing the positions of the head and shoulder markers, the hat of the suit would need to be placed in the exact same orientation during each testing session to ensure that head marker orientation is consistent. Finally, with current knowledge on the difficulties of performing the pull-to-sit task, the end of the action could be more exactly defined, leaving less ambiguity in the data labeling and analysis.

5.1.2.3 Visual Tracking

5.1.2.3.1 Visual Tracking: Quantitative Conclusions and Modifications

The results indicated no difference between the high- and low-risk populations. Because there was only one usable trial from the high-risk population,

PCA was unable to be performed and statistical analysis did not yield significant results. Additional data is needed to clarify the relationship between these two groups.

5.1.2.3.2 Visual Tracking: Qualitative Conclusions and Modifications

As in the previous two actions, the visual tracking task often did not hold the infant's interest. When the participant lost interest in our simple, cylindrical object, we held a second object that played music behind the marker-tagged tube, introducing possible undesired variability. In future implementation of this task, the primary toy should be made to be more stimulating for the infant, possibly by introducing sound.

Additional modifications to the task are similar to those discussed for reach-to-grasp and pull-to-sit, and would serve to better standardize the task. First, the hat must be placed on the infant's head in the same orientation every capture session, as these three markers were used to track head movement with the object.

Second, it is widely accepted that an infant's gaze likes to fixate on faces, which created another methodological flaw and source of variability in the visual tracking task. We aimed to examine how well an infant could track an object from their midline to both their left and right periphery, and then back to the midline. But during this action, the infant's gaze had many opportunities to fall on the primary and secondary researchers' faces, as well as the parent's face. Therefore when the infant did not track the object for the duration of the task, we were unsure if the results spoke to their inability to follow an object, or if the participants were simply more interested in individual faces. A better way to implement this task would be to

develop an apparatus that moves the object from the center to the periphery and back without the need for a researcher to be present. Not only would this eliminate facial distractions for the infant, but the test could also be administered with more consistency.

5.1.2.4 Postural Control

5.1.2.4.1 Postural Control: Quantitative Conclusions and Modifications

The postural control task was unable to be analyzed because of a lack of motion capture data. While playing with the toys used during the postural control task, the infant's arms would often occlude the chest marker. The occlusion of the chest marker prevented the camera system from seeing the three-point rigid body formed by the shoulder and chest marker. Without the rigid body, changes in the infant's posture were unable to be detected.

5.1.2.4.2 Postural Control: Qualitative Conclusions and Modifications

Deficiencies in the postural control task were perhaps the most extensive of the four actions performed in this study. Problems with infant cooperation, the motion capture system, and task design, combined to make the data collected in this task unusable, if data was obtained at all.

Infant cooperation issues were immediately apparent, with the participant often not interested enough in the cylindrical tube object. If the infant did grasp the object, on many occasions he would not shake or play with the tube. Shaking was essential to revealing if the participant could maintain his posture while he was

moving his upper body. Furthermore, the infant would often drop the toy soon after originally picking it up. Our methodology also called for the light object to be exchanged with a heavier object after one minute of play. This exchange was likely to induce a tantrum, as we were taking an object away from the infant. This tantrum would often preclude us from completing this task to the designed specifications.

The issues with postural control did not end if the infant was cooperative. Unfortunately, when the infant did shake or play with the object, marker occlusion often occurred. The chest marker was lost for extended periods of time, making data analysis impossible. Without the chest marker, the only marker indicating trunk posture was eliminated.

Given that no data was analyzable for the postural control task, we have several ideas for improving the administration of the task. The first changes that would be considered are the toys. As with the reach-to-grasp and the visual tracking task, we would replace the toys with more interesting objects that make noise or play music. Also, we believe that the administration of the test would benefit from an increase in the mass of our heavy object, as this would increase the strain placed on the infant to maintain their balance. Increasing the demands placed on the balance of the infant may elicit more readily identifiable differences in the postural control of infants.

To solve the aforementioned problem of chest marker occlusion, we have ideas to modify both marker placement and suit design. A possible simple solution would be to place a marker on the infant's back instead of the chest. This would

allow the infant to play uninhibited with the object and the cameras to maintain an uninhibited line of sight to the torso marker. A more complex solution would be to add markers to the suit, lining the infant's spinal column. This approach may provide a more nuanced picture of how the infants stabilize themselves and control their posture when they are reaching for and interacting with the light and heavy objects.

To fully realize the benefits of lining the spinal column with markers, a motion capture system with higher resolution cameras would be necessary. With higher resolution cameras, the reflective markers could be placed closer together, thus affording researchers access to more data inputs. Beyond just postural control, higher resolution cameras would allow the size of the reflective markers to be reduced, making the markers less intrusive to the infant and allowing more markers to be placed on the infant. We had to remove markers from our pilot session motion capture suit because points were too close together, causing the OptiTrack system to collapse two markers into one. This type of problem would be greatly diminished with higher resolution cameras. Additionally, increasing the total number of markers would increase the number of analyzable parameters, while also allowing the motion capture suit to be optimized for more actions at any given time.

While lining the spine with reflective markers is a possible solution, postural control tasks investigated in this manner may be better suited for an active motion capture system. Although the possibility that blinking LEDs in active motion capture may distract infants was discussed earlier, this may not be an issue if the markers were on the infant's back. Inertial motion capture systems are also a possibility to

deal with the issue of marker occlusion as they do not require line of sight from the cameras to the markers.

5.1.3 System Viability

Based on the statistically significant results of the reach-to-grasp task, this study demonstrated that our motion capture framework and suit design were capable of discerning subtle differences in motion. However, the lack of data for certain actions and the qualitative conclusions discussed for each task show that significant limitations exist, such as frequent marker occlusion, point flickering and point jumping. These limiting factors led to large amounts of unusable data and indicate that further tests and modifications are required before this system can be used on a wide scale.

More expensive hardware and software would resolve many of the issues we faced with the OptiTrack system. For example, camera systems with higher resolution would allow for a suit with more closely spaced markers. This would have been especially important for the postural control task, where as discussed in Qualitative Conclusions, markers along the spinal cord could have yielded usable data. However such camera systems typically cost greater than \$50,000, while the OptiTrack system used in this study was approximately \$10,000. Similarly, more expensive software would have eliminated problems of point jumping in the raw data collection, leading to more usable data. Therefore given financial constraints, we conclude that our system and suit provide a relatively inexpensive and reliable method to study infant movement.

However, significant additional testing is needed to validate this claim. As discussed, two additional significant limitations came from variability in task design and execution, and from small sample sizes. Repeating this project with the modifications discussed in the Qualitative Conclusions sections, as well as further changes enumerated in Future Directions, and with more infant participants would more robustly support the viability of our system.

In addition, analysis of statistical data often uses some kind of smoothing algorithm to remove noise and emphasize critical data. While we used linear interpolation to fill in missing data when the amount of missing data was small, no further smoothing was implemented in our data analysis. TrackingTools produces very reliable quantitative data unless it loses points, and we did not expect to have any problems with noise. When indicators are occluded, however, TrackingTools may encounter problems calculating the location of markers. As such, future researchers using this system should use a smoothing algorithm such as a Kalman filter.

5.2 Implications

This study sought to answer the following question - what quantifiable differences in the movements of infants at high and low risk for ASD can passive motion capture technology detect? Because of the small sample size, we cannot make strong claims to the implications of our statistically significant findings in the reach-to-grasp and pull-to-sit tasks for movement and ASD. These findings are consistent with current literature and merit additional study.

However, the custom-designed infant suit and motion indicator extraction code are novel contributions that further current knowledge on the ability of motion capture technology to detect abnormalities in infant movement. The implications of these two portions of our project are discussed below.

5.2.1 Infant Suit

The process and goals of suit design were not well-documented and had not been explicitly stated in previous literature. Having adjusted marker size and placement to accommodate the limitations of the camera system and designated tasks, we have enumerated a process to speed future suit designs. Also, the concepts of modularity and connected components are taken from such seemingly distant fields as graph theory and applied to make the goals of the suit more tangible and testable. The placement of rigid bodies on the same piece of the suit and use of separate pieces gives the suit flexibility and replicability of marker spatial relations. This consistency allows for easier analysis of the resulting data.

These new applications of simple concepts are an important contribution to the field of motion capture, especially in working with infants. Infant populations present difficulties from a social and technical perspective. Actions can not be verbally communicated with infants, and their small body frames make it difficult to put the requisite three markers on a body segment to represent a rigid body. Having designed a motion capture suit for infants is an important contribution to the endeavor to find possible movement indicators of ASD. This suit provides a model which others can imitate and improve upon.

5.2.2 Code base

Although the code written for this study was specifically designed to work with the .CSV files created by the Natural Point Tracking Tools software, it can be used to study infant motion in a variety of capacities. The code allows for labeling of our custom suit design, which had specifications that were not supported by the Tracking Tools software. Therefore if a researcher wanted to adapt any motion capture system that outputs readable code to a new suit design, she could use principles from our open source code, such as our labeling by proximity and modeling techniques. This is especially significant for the study of motion and ASD, as the current impetus lies in studying movement as an early indicator for ASD and motion capture setups have been documented to perform fewer infant than adult studies.

5.3 Limitations of the Study

Task-specific flaws in design, execution, and analysis were already discussed in section 5.1 of this chapter. Here, we discuss the implications of the following more broad limitations - small sample size, variability in task execution, and imperfections in the data analysis protocol.

Primarily, this study suffered from a small sample size. With only three high risk participants, we have little confidence that our sample is representative and can yield reliable statistical results uninfluenced by confounding variables and selection biases.

Second, variability in task execution was significant, as described for each action in the Qualitative Conclusions sections. While every effort was made to adhere to a stringent protocol, the first priority was the comfort of the child, and the second was obtaining whatever data possible given the child's temperament that day. Therefore the protocols had to be tailored to each child and modified drastically in some cases of extremely uncooperative behavior. Modifications included the order of the tasks, the number of trials per action, the presence of a parent in the room, the time between tasks, the activities between tasks, and the substitution of the mother for primary researcher. Given what was learned for each task, more specific guidelines could be established that also take lack of infant cooperation into account.

Third, the data analysis protocol introduced some potential error to the project. The labeling algorithm was not perfect, but performed well with a very low error incidence. To determine its exact accuracy, the algorithm would need to undergo a more rigorous 'ground truth' comparison. This vetting process would involve multiple human operators manually labeling each point in every frame of a sample data file, and comparing these results to the algorithm output. However, the human-labeled ground truth would have its own potential for human error, and the accuracy value would not be entirely reliable because accuracy of the algorithm is dependent on the data being labeled.

In lieu of this process, random spot-checked observations were conducted during data processing to estimate the error incidence, and data collection was quality-controlled by the computer operator to ensure that the data was of sufficient

quality. When data had more instances of points that flickered, jumped, or moved close together, the accuracy tended to be a bit lower. When points moved smoothly and no data collection anomalies occurred, the algorithm was observed to operate at almost 100% accuracy.

Another limitation of the labeling process was the manual labeling of the first frame of each task, prior to use of the algorithm. Since this was not done by multiple reviewers, the process introduced potential for human error.

An additional potential inconsistency in the data analysis is that the actual start and end frames for an action are not well defined concepts. In our analysis, the start and end frames were selected as the frame in which the point of interest began and finished its movement. This method was not infallible, because small movements were present at all times. Also, the selection was done visually by researchers watching videos in slow-motion, introducing the potential for human error.

5.4 Future Directions

For any proof of concept study, the most natural follow-up research is to take the lessons learned from the implementation of the methodology and apply them to a study with a much larger sample size. Thus, with the modifications discussed in the Qualitative Conclusions and Limitations sections, as well as a larger high-risk infant population, we propose repeating the study as the first future direction.

Specifically, our most promising results, those obtained from the reach-to-grasp task, merit further investigation. The motion indicator of reach-to-grasp average velocity should be further studied to first confirm the significance thereof. If

this finding can be replicated, steps could be taken to develop a preliminary diagnosis based on the indicator that can be applied to young children. This advancement in diagnosis age would allow children to be placed in appropriate programs earlier, greatly increasing the child's ability to lead a healthy and fulfilling life.

Another unexplored technique that could be used in a future iteration of this study is the analysis of PCA output through the use of machine learning. Compared to the Welch's t-test that we ran on the PCA output, machine learning techniques are much more complex, and could potentially identify significant results where the t-test failed. However, machine learning algorithms require larger amounts of data, because some of that data must be used to 'teach' the algorithm what to look for. With a larger sample size, machine learning may be able to recognize subtleties in movement that this study was not able to discern.

Furthermore, as autism cannot be reliably diagnosed at the age of 12 months, a second logical follow up to this project is to add a longitudinal component. With the parents consent, the diagnostic status of the both the high and low risk infants would be tracked. If an infant from either of our experimental groups is diagnosed with an ASD, this information could be used to reinterpret the data that was collected in this study. Algorithms could be focused on determining what made the movements of a particular infant unique from those of the other infants, given their diagnostic status. When the diagnosis is first made, a second motion capture session could also be used to quantify aspects of their maturing motor system. Even if no infants are ultimately diagnosed with an ASD, it would be interesting to note if any infants go

through any type of occupational therapy addressing motor deficiencies. This information could also be used to refocus analysis techniques on the particular infant.

Appendices

Appendix A – IRB application and addenda with selected supplementary documents

Appendix A.1 – IRB Initial Application

Name of Principal Investigator (PI)
or Project Faculty Advisor
(NOT a student or fellow) Yiannis Aloimonos **Tel. No.** [REDACTED]

Name of Co-Investigator (Co-PI) _____ **Tel. No.** _____

E-Mail Address of PI yiannis@cs.umd.edu **E-Mail Address of Co-PI** _____
Name and address of contact to receive approval documents Yiannis Aloimonos

Name of Student Investigator Brendan Wray **Tel. No.** [REDACTED]

E-Mail Address of Student Investigator bwray1@umd.edu
Check here if this is a student master's thesis or a dissertation research project

Department or Unit Administering the Project _____

Project Title Analyzing the movement of infants at risk for autism spectrum disorders

Funding Agency: ORAA Proposal ID Number: Names of any additional Federal agencies providing funds or other support for this research project:
--

Target Population: The study population will include (Check all that apply):

- | | | |
|---|------------------------------------|---|
| <input type="checkbox"/> pregnant women | <input type="checkbox"/> neonates | <input type="checkbox"/> individuals with mental disabilities |
| <input checked="" type="checkbox"/> minors/children | <input type="checkbox"/> prisoners | <input type="checkbox"/> individuals with physical disabilities |
| <input type="checkbox"/> human fetuses | <input type="checkbox"/> students | |

Exempt or Nonexempt (Optional): You may recommend your research for exemption or nonexemption by checking the appropriate box below. For exempt recommendation, list the numbers for the exempt category(s) that apply. Refer to pages 6-7 of this document.

Exempt ---List Exemption Category(s)	Or	X Non-Exempt
If exempt, briefly describe the reason(s) for exemption.		

Date **Signature of Principal Investigator or Faculty Advisor**

Date **Signature of Co-Principal Investigator**

Date **Signature of Student Investigator**

Date **REQUIRED Departmental Signature**

Name _____,
Title _____

(Please also print name of person signing above)

(PLEASE NOTE: The Departmental signature block should not be signed by the investigator or the student investigator's advisor.)

For Internal Use Only (to be completed by the IRB Office)	Application #:
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Abstract

Provide an abstract (no more than 200 words) that describes the purpose of this research and summarizes the strategies used to protect human subjects. For HHS sponsored or funded research, you must submit a copy of your grant application for review.

1. Current research suggests that autism spectrum disorders (ASD) negatively affect motor development. Among experts, it is widely accepted that early intervention is the most effective method for improving quality of life for individuals with ASD. This study proposes to determine whether or not the effect of ASD on motor development can be used as an early indicator for identifying infants displaying characteristics of ASD. Using motion capture technology, the movements of infants at high risk of ASD will be compared to the movements of those at low risk. Specific movements of interest include head lag, as demonstrated in a pull-to-sit task, and arm trajectory exhibited in reaching for an object. In analyzing the collected data, it is expected that a discernible difference in movement will be detected. If results are as expected, this study will lay the foundation for the creation of a developmental benchmark intended to identify infants displaying early indicators of ASD. In order to minimize the risks associated with this study, participants will be allowed to dictate the pace of the research sessions and all confidential materials will be stored in a secure facility.

Subject Selection

a. Who will be the subjects? How will you recruit them? If you plan to advertise for subjects, please include a copy of the advertisement. b. Will the subjects be selected for any specific characteristics? (e.g., age, sex, subjects, ethnic origin, religion, or any social or economic qualifications? c. State why the selection will be made on the basis or bases given in 2(b). d. How many subjects will you recruit?

- 2a. This study will have three participant groups, infants aged 6-10 months old with an older sibling with a confirmed diagnosis of ASD (high-risk participant), infants aged 6-10 months old with no family history of ASD (low-risk participant) and one parent for each sibling or pair of siblings. While probands and other older siblings of the infant participants will not be directly participating in the study, information will be gathered about their development through parent questionnaires to determine the eligibility of their infant siblings for either the high-risk or low-risk group. Flyers identical to that found in Appendix A will be used to recruit participants. Flyers will be hung off campus at the Autism Center at the Kennedy Krieger Institute located in Baltimore, MD and will also be distributed to patients at the Autism Center by Kennedy Krieger staff. Remuneration of 10 dollars will be given after completion of testing to defray the costs of transportation and parking.

- 2b. The subjects for this study will be selected based upon several criteria. Primarily, we will ensure that each proband meets the criteria for ASD through administration of the Social Communication Questionnaire (SCQ) found in Appendix B, using a score of 11 or higher as criteria for ASD. The proband must also have received a diagnosis of ASD from a professional. Through administration of the 15-minute telephone eligibility screening (Appendix C), factors excluding the infant will be determined. These factors are (1) failed hearing or vision screening conducted by pediatrician's office, audiologist, or ophthalmologist; (2) severe birth trauma or any genetic anomaly that may create risk for survival; and (3) head injury for both low- and high-risk participants. Also, potential low-risk participants will be excluded if they have a family history of ASD. Further, infant participants as well as probands must have weighed at least 2250g (4.96 pounds) at birth and must have been born after 36 weeks gestation.
- 2c. These exclusions are made to ensure infant participants can hear and see instructions given during testing and to prevent introducing factors that may indicate developmental delays.
- 2d. For our study, we expect to recruit approximately 120 individuals, of which we expect 100 to pass the telephone eligibility screening in Appendix C and to agree to participate. We expect 25 high-risk participants, 25 low-risk participants, and one parent for each participant (50 parents). All participating families will receive \$10 as compensation for their time and transportation.

Procedures

What precisely will be done to the subjects? Describe in detail your methods and procedures in terms of what will be done to subjects. How many subjects are being recruited? What is the total investment of time of the subjects? If subjects will complete surveys and/or other instruments on more than one occasion, state this in the procedures section. If you are using a questionnaire or handout, please include a copy within each set of application documents. If you are conducting a focus group, include a list of the questions for the focus group. If you plan to collect or study existing data, documents, records, pathological specimens or diagnostic specimens, state whether the sources are publicly available and if the information will be recorded in such a manner that subjects can be identified, directly or through identifiers linked to the subjects. If you are collecting or studying existing data, describe the dataset and list the data elements that you will extract from the dataset.

3. Our methods and procedures will involve two distinct phases: eligibility screening over the phone and the data collection phase that will take place at the University of Maryland, College Park. The eligibility screening consists of two parts conducted over the telephone. First is the administration of the SCQ (Appendix B), which assesses communication and social skills. This questionnaire,

which will take roughly 10 minutes per child, will be completed by the parents over the phone, for all siblings of potential infant participants. For this study we are using a score of 11 to indicate ASD. An infant participant can only be eligible for the high-risk group if one or more of their siblings (proband) score(s) 11 or higher and has a diagnosis of ASD from a qualified physician. An infant cannot be chosen as a low-risk participant if any of their siblings score 11 or higher. The second part of eligibility testing is a 15-minute eligibility interview (Appendix C) which covers all of the exclusionary criteria of this study. The participation of the siblings in this study is strictly limited to eligibility testing to determine whether the infant is eligible to participate. Neither the proband nor any siblings of the infant need to attend the motion capture portion of testing as they will not be involved in motion capture data collection.

For our study, we expect to recruit approximately 120 individuals, of whom we expect to select 100 participants who will have passed both parts of the eligibility screening. We expect to find 25 high-risk participants, 25 low-risk participants, and have one parent accompanying each participant (50 parents), for a total of 100 participants.

During the eligibility screening over the phone, an address will be obtained to send a packet of questionnaires after confirming a participant's eligibility and willingness to participate. These questionnaires are to be completed by the parents before their scheduled data collection session. The first questionnaire, the intake questionnaire (Appendix D), will allow the parent to check off from a list any concerns that they may have about their child and write any additional concerns. This questionnaire will take roughly five minutes to complete. The second questionnaire, the Rothbart Infant Behavior Questionnaire (Appendix E), will measure scales of temperament including activity level, attention, and placability. This questionnaire will take approximately 60 minutes to complete. The final questionnaire, the Communication and Symbolic Behavior Scales (CSBS) Caregiver questionnaire (Appendix F), will provide information regarding communicative functions and gestures, as well as vocal and verbal communicative means, reciprocity, social-affective signaling, and symbolic behavior. This questionnaire will require approximately ten minutes to complete and has been standardized for newborn to three-year-old infants.

For the second phase of the project, the participants will be asked to come to the University of Maryland, College Park (UMCP) to complete a 60-90 minute testing session. Only one visit will need to be scheduled for each participant. The testing session will be held in the Keck Laboratory of the AV Williams building at UMCP. Before any interaction between the researchers and infant occurs, parents will be asked to read and sign both the informed consent form (Appendix G) and

HIPAA privacy authorization form (Appendix H). Parents will be able to ask the researchers any questions and clarify any concerns with the study and procedures at this time. The consequent session will consist of an infant object exploration task and infant motion capture followed by a brief parent follow-up questionnaire. The data collection session will begin with one of three researchers measuring the circumference of the infant's head using both a tape measure and calipers while a second researcher handles the infant, along with recording the infant's height and weight.

The infant will then complete a five-minute object exploration assessment. In the first three minutes, the infant will be able to explore three novel toys (e.g. a stretchy toy, a noisemaker, and a nubby ball) in any manner. Exploration will be coded for functional use of the toy and repetitive actions characteristic of autism (such as spinning, close examination, or flicking). During the last two minutes of the assessment, spontaneous imitation with the toys will be tested. The researchers will perform a novel action with a toy and then give it to the child without providing any verbal or physical prompting. The examiner will then wait 30 seconds to see if the child imitates the action. After those 30 seconds, the initial action on the toy is repeated once again, after which the child is given a chance to imitate again.

Next, the researchers will prepare the infant for the motion capture portion of the session, in which the child will perform a pull-to-sit and a reaching task. A third researcher will operate the motion capture system. Before the motor tracking begins, several adhesive 5/8-inch (or 4mm) reflective markers will be placed on the participant's body at predetermined locations. In the pull-to-sit task, a researcher will grasp the infant's hands and gently pull the infant from a supine position to a sitting position; from this, the motion capture system will measure degrees of head lag. In the reaching task, a researcher will place the infant in a supine position and stimulate reaching by holding a small toy above the infant's chest. During this task, the motion capture system will measure the velocities of the hand, forearm, and upper arm, as well as leg posture, trunk posture, and total movement time. Each task will be performed three times, and data will be collected by the motion capture system throughout.

After the infant performs the two required tasks, he or she will be placed in a supine position on mats in the laboratory near a few toys and allowed five minutes for free motion. The purpose of this unrestricted motion is to capture data from movement of joints not included in the two tasks. Analysis of this data will allow a more comprehensive characterization of differences in motion between the high-risk and low-risk infants. During each trial, the infant will be placed in a supine position with access to a set of toys. Grayscale video will also be taken by the

system in each task with permission of the parent of the participant as indicated on the informed consent form (Appendix G).

Upon completion of the motion capture portion of the session, the parent will be asked to complete a final questionnaire, the CSBS Parent Perception questionnaire (Appendix J). This five-minute questionnaire allows the parent to rate their child's performance at the conclusion of testing as to whether aspects of their behavior were less than typical, typical, or more than typical. The completion of this questionnaire concludes the testing session and the parent, infant, and sibling's participation in the research.

The total time expected for the participants to commit will be two and a half to three hours filling out questionnaires and reading the informed consent and privacy authorization forms, and 30 minutes to one hour preparing for and completing the motion capture session.

Risks and Benefits

Are there any risks to the subjects? If so, what are these risks including physical, psychological, social, legal and financial risks? Please do not describe the risk(s) as minimal. If there are known risks, please list them. If not, please state that there are no known risks. What are the benefits? If there are known risks associated with the subject's participation in the research, what potential benefits will accrue to justify taking these risks?

4. Some participants may get tired or uncomfortable while performing the pull-to-sit, reach, and free motion tasks. If the parent or infant expresses discomfort or fatigue, the testing will be stopped until the parent deems the child ready to begin again. Other physical risks include injury that may occur during any of these tasks. Two trained researchers from the Autism Center at the Kennedy Krieger Institute will handle the infant participants to minimize these risks. Some people may also be uncomfortable being videotaped, or answering personal questions. Parents do not have to answer any questions that they are uncomfortable answering. Parents are free to ask questions at any time during the study.

A potential legal risk is a loss of confidentiality, which is discussed in greater detail in the next section. Finally, participants will have to pay for the cost of transportation to the University, as well as parking.

There are no direct health benefits to participating parents and their infants. The results may help the investigator and the public learn more about motor development in children at a high-risk for autism spectrum disorder and those at a low-risk. We hope that, in the future, other people may benefit from this study through improved understanding of autism spectrum disorders.

Confidentiality

Adequate provisions must be made to protect the privacy of subjects and to maintain the confidentiality of identifiable information. Explain how your procedures accomplish this objective, including such information as the means of data storage, data location and duration, description of persons with access to the data, and the method of destroying the data when completed. If the research involves audio taping, videotaping or digital recordings, state who will have access to the tapes or recordings, where the tapes or recordings will be kept, and state the final disposition of the tapes or recordings (i.e. Will the tapes or recordings be destroyed? If so, when will the tapes or recordings be destroyed?). Please note that as per the University of Maryland policy on records retention and disposal, all human subject files, including work done by faculty, staff, and students, must be retained for a period of no less than 10 years after the completion of the research and can then be destroyed. Human subject files include IRB applications, approval notices, consent forms, and other related documents. For more information on records retention, go to: http://www.dbs.umd.edu/records_forms/schedule.php (Faculty and Academic Records) or contact Michelle Solter Evers, Assistant to the Director of Business Services at 301.405.9277 or mevers@mercury.umd.edu.

5. We will take all possible steps to maintain participant confidentiality. All participants will be randomly assigned identification numbers, which will be written on a single document stored in a locked cabinet at the Kennedy Krieger Institute Center for Autism and Related Disorders. The data collection is not being performed at the Kennedy Krieger Institute, but it provides a secure location to store documents containing participant's Protected Health Information. Access to this master list will only be provided to research staff creating and maintaining the participant database, and research staff scheduling the study visits.

Forms containing personal data will be stored in locked cabinets at the Kennedy Krieger Institute. Personal information that is entered into databases will remain on secured computer files, and will not be kept in mainframe files. These databases will not contain patient names, and will instead use the randomly assigned patient identification numbers. Access to the database and files will only be provided to research staff required to enter data, score and check test results, and file participant information.

Photographs and videos will be taken digitally and will also be stored on the secured computers at the Kennedy Krieger Institute. These picture and video files will only be identified by the randomly assigned participant identification numbers. Only research staff will have access to the photographs and videos.

Data collected from participants that are determined to be ineligible or do not consent will be destroyed within a week.

Information and Consent Forms

State specifically what information will be provided to the subjects about the investigation. Is any of this information deceptive? State how the subjects' informed consent will be obtained. Will you obtain informed consent in a language other than English? If so, list the language(s) in which you will obtain informed consent. Provide consent forms in all languages that will be used. Refer to the attached consent form template, sample consent form and additional consent form guidance on pages 9 to 18. If a consent form has more than one page, please add a signature and date line and the number of pages (e.g., "1 of 2," "2 of 2") to each page. Please allow a 2-inch bottom margin to accommodate the IRB approval stamp. If you plan to obtain consent over the telephone (e.g. consent for a telephone survey), include a copy of the consent script.

6. Subjects participating in the motion capture sessions will be infants aged 6 to 10 months and unable to comprehend our investigation. Prior to acceptance into the research study, the parent(s) or legal guardian(s) of each infant will be given a full description of the investigation procedures and an explanation of what kind of data will be collected and how it will be used for the research study (see Appendix C, p. 1). Parents/Guardians will be informed about the details of the motion capture equipment, and each of the three stages of movement data collection. Additionally, we will explain that we are looking for patterns of movement in the infants and that we plan to compare the movement of the low-risk group with that of the high-risk group, and that we hope to find reliable distinctions between the data sets. While we will explain that we are looking for differences between the two groups we will inform the parent(s) or guardian(s) that we are not qualified to offer any information relating to a diagnosis of ASD.

No deceptive information will be given to the participants. Informed consent will be obtained via a consent form with a comprehensive description of the study included with it. All participants will be provided a copy of the consent form for their records. English will be the only language used to obtain consent. Please see Appendix G for the informed consent form.

Conflict of Interest

Describe the potential conflict of interest, including how such a conflict would affect the level of risk to the study participants. Please consult the University of Maryland policy on conflict of interest as defined by the University of Maryland Policies and Procedures III-1.11 and II-3.10. These may be viewed at: <http://www.usmh.usmd.edu/Leadership/BoardOfRegents/Bylaws/SectionIII/III111.html>. If there is no anticipated conflict of interest, please state "No conflict of interest." This section must be included in your application.

7. No conflict of interest.

HIPAA Compliance

State whether you are using HIPAA protected health information (PHI). Currently, researchers employed by the University of Maryland Center or who are working within or under the auspices of the University Health Center are subject to specific HIPAA requirements regarding the creation, use, disclosure, or access of PHI. Please consult the University of Maryland's Summary of HIPAA's Impact on University Research. For more information on HIPAA, go to: <http://www.hhs.gov/ocr/hipaa/> If you are not using HIPAA protected health information, please state "Not Applicable." This section must be included in your application.

8. We will be using HIPAA protected information and will be using a privacy authorization form (Appendix H). All participants will receive a copy of the authorization form for their records.

Research Outside of the United States

Provide responses to the following questions. Separate responses are required for each country where the research will be conducted. If you are not conducting research outside the U.S., please state "Not Applicable." This section must be included in your application.

- a) *Did the investigator(s) previously conduct research in the country where the research will take place? Briefly describe the investigator's knowledge and experience working with the study population.*
- b) *Are there any regulations, rules or policies for human subjects research in the country where the research will take place? If so, please describe and explain how you will comply with the local human subject protection requirements. The United States Department of Health and Human Services, Office for Human Research Protections (OHRP) has an International Compilation of Human Subject Research Protections with a listing of the laws, regulations and guidelines of over 50 countries. This compilation can be accessed on the OHRP website: <http://www.hhs.gov/ohrp/international/HSPCompilation.pdf>*
- c) *Do you anticipate any risks to the research participants in the country where the research will take place, taking into account the population involved, the geographic location, and the culture? If so, please describe, including any physical, psychological, social, legal and financial risks. Do you anticipate that subjects who participate in this research will be placed at risk of criminal or civil liability? If so, please describe.*

9. Not Applicable.

Research Involving Prisoners

Provide responses to the following additional IRB criteria for research involving prisoners. If you are not conducting research involving prisoners, please state "Not Applicable." This section must be included in your application.

- a) *the research under review represents one of the categories of research permissible described below;*
 - i. *study of the possible causes, effects, and processes of incarceration, and of criminal behavior; provided that the study presents no more than minimal risk and no more than inconvenience to the subjects;*
 - ii. *study of prisons as institutional structures or of prisoners as incarcerated persons, provided that the study presents no more than minimal risk and no more than inconvenience to the subjects;*
 - iii. *research on conditions particularly affecting prisoners as a class (for example, vaccine trials and other research on hepatitis which is much more prevalent in prisons than elsewhere; and research on social and psychological problems such as alcoholism, drug addiction, and sexual assaults); or*
 - iv. *research on practices, both innovative and accepted, which have the intent and reasonable probability of improving the health or well-being of the subject.*
- b) *any possible advantages accruing to the prisoner through his or her participation in the research, when compared to the general living conditions, medical care, quality of food, amenities and opportunity for earnings in the prison, are not of such a magnitude that his or her ability to weigh the risks of the research against the value of such advantages in the limited choice environment of the prison is impaired;*
- c) *the risks involved in the research are commensurate with risks that would be accepted by nonprisoner volunteers;*
- d) *procedures for the selection of subjects within the prison are fair to all prisoners and immune from arbitrary intervention by prison authorities or prisoners. Unless the principal investigator provides to the Board justification in writing for following some other procedures, control subjects must be selected randomly from the group of available prisoners who meet the characteristics needed for that particular research project;*
- e) *the information is presented in language which is understandable to the subject population;*
- f) *adequate assurance exists that parole boards will not take into account a prisoner's participation in the research in making decisions regarding parole, and each prisoner is clearly informed in advance that participation in the research will have no effect on his or her parole; and if there is a need for follow-up examination or care of participants after the end of their participation, adequate provision has been made for such examination or care, taking into account the varying lengths of individual prisoners' sentences, and for informing participants of this fact.*

10. Not Applicable.

Infant Behavior Questionnaire - Revised

Subject No. _____ Date of Baby's Birth _____

 month. day year
 Today's Date _____ Age of Child _____

 mos. weeks
 Sex of Child _____

INSTRUCTIONS:

Please read carefully before starting:

As you read each description of the baby's behavior below, please indicate how often the baby did this during the LAST WEEK (the past seven days) by circling one of the numbers in the left column. These numbers indicate how often you observed the behavior described during the last week.

		Less Than					
	Very	Half the	About Half	More Than	Almost		Does Not
<u>Never</u>	<u>Rarely</u>	<u>Time</u>	<u>the Time</u>	<u>Half the Time</u>	<u>Always</u>	<u>Always</u>	<u>Apply</u>
1	2	3	4	5	6	7	X

The "Does Not Apply" (X) column is used when you did not see the baby in the situation described during the last week. For example, if the situation mentions the baby having to wait for food or liquids and there was no time during the last week when the baby had to wait, circle the (X) column. "Does Not Apply" is different from "Never" (1). "Never" is used when you saw the baby in the situation but the baby never engaged in the behavior listed during the last week. For example, if the baby did have to wait for food or liquids at least once but never cried loudly while waiting, circle the (1) column.

Please be sure to circle a number for every item.

Feeding

Office Only

During feeding, how often did the baby:

- 1 2 3 4 5 6 7 X (1) lie or sit quietly? 1. ____
- 1 2 3 4 5 6 7 X (2) squirm or kick? 2. ____
- 1 2 3 4 5 6 7 X (3) wave arms? 3. ____
- 1 2 3 4 5 6 7 X (4) notice lumpy texture in food (e.g., oatmeal)? 4. ____

In the last week, while being fed in your lap, how often did the baby:

- 1 2 3 4 5 6 7 X (5) seem to enjoy the closeness? 5. ____
- 1 2 3 4 5 6 7 X (6) snuggle even after she was done? 6. ____
- 1 2 3 4 5 6 7 X (7) seem eager to get away as soon as the feeding was over? 7. ____

How often did your baby make talking sounds:

- 1 2 3 4 5 6 7 X (8) while waiting in a high chair for food? 8. ____
- 1 2 3 4 5 6 7 X (9) when s/he was ready for more food? 9. ____
- 1 2 3 4 5 6 7 X (10) when s/he has had enough to eat? 10. ____

Sleeping

Before falling asleep at night during the last week, how often did the baby:

- 1 2 3 4 5 6 7 X (11) show no fussing or crying? 11. ____

During sleep, how often did the baby:

- 1 2 3 4 5 6 7 X (12) toss about in the crib? 12. ____
- 1 2 3 4 5 6 7 X (13) move from the middle to the end of the crib? 13. ____
- 1 2 3 4 5 6 7 X (14) sleep in one position only? 14. ____

After sleeping, how often did the baby:

- 1 2 3 4 5 6 7 X (15) fuss or cry immediately? 15. ____

1 2 3 4 5 6 7 X (16) play quietly in the
crib? 16. ____

1 2 3 4 5 6 7 X (17) cry if someone doesn't come within a few minutes?
17. ____

How often did the baby:

1 2 3 4 5 6 7 X (18) seem angry (crying and fussing) when you
left 18. ____
her/him in the

crib?
1 2 3 4 5 6 7 X (19) seem contented when left in the
crib? 19. ____

1 2 3 4 5 6 7 X (20) cry or fuss before going to sleep for
naps? 20. ____

When going to sleep at night, how often did your baby:

1 2 3 4 5 6 7 X (21) fall asleep within 10
minutes? 21. ____

1 2 3 4 5 6 7 X (22) have a hard time settling down to
sleep? 22. ____

1 2 3 4 5 6 7 X (23) settle down to sleep
easily? 23. ____

Office Only

When your baby awoke at night, how often did s/he:

1 2 3 4 5 6 7 X (24) have a hard time going back to
sleep? 24. ____

1 2 3 4 5 6 7 X (25) go back to sleep
immediately? 25. ____

When put down for a nap, how often did your baby:

1 2 3 4 5 6 7 X (26) stay awake for a long
time? 26. ____

1 2 3 4 5 6 7 X (27) go to sleep
immediately? 27. ____

1 2 3 4 5 6 7 X (28) settle down
quickly? 28. ____

1 2 3 4 5 6 7 X (29) have a hard time settling
down? 29. ____

When it was time for bed or a nap and your baby did not want to go, how often did s/he:

1 2 3 4 5 6 7 X (30) whimper or
sob? 30. ____

1 2 3 4 5 6 7 X (31) become
tearful? 31. ____

Bathing and Dressing

When being dressed or undressed during the last week, how often did the baby:

1 2 3 4 5 6 7 X (32) wave her/his arms and
kick? 32. ____

1 2 3 4 5 6 7 X (33) squirm and/or try to roll
away? 33. ____

1 2 3 4 5 6 7 X (34) smile or
laugh? 34. ____

1 2 3 4 5 6 7 X (35) coo or
vocalize? 35. ____

When put into the bath water, how often did the baby:

1 2 3 4 5 6 7 X (36)
smile? 36. ____

1 2 3 4 5 6 7 X (37)
laugh? 37. ____

1 2 3 4 5 6 7 X (38) splash or
kick? 38. ____

1 2 3 4 5 6 7 X (39) turn body and/or
squirm? 39. ____

When face was washed, how often did the baby:

1 2 3 4 5 6 7 X (40) smile or
laugh? 40. ____

1 2 3 4 5 6 7 X (41) fuss or
cry? 41. ____

1 2 3 4 5 6 7 X (42)
coo? 42. ____

When hair was washed, how often did the baby:

1 2 3 4 5 6 7 X (43)
smile? 43. ____

1 2 3 4 5 6 7 X (44) fuss or
cry? 44. ____

1 2 3 4 5 6 7 X (45)
vocalize? 45. ____

Play

Office Only

How often during the last week did the baby:

1 2 3 4 5 6 7 X (46) look at pictures in books and/or magazines
for 46. ____

2-5 minutes at a time?

1 2 3 4 5 6 7 X (47) look at pictures in books and/or magazines
for 47. ____

5 minutes or longer at a time?

1 2 3 4 5 6 7 X (48) stare at a mobile, crib bumper or picture
for 48. ____

5 minutes or longer?

1 2 3 4 5 6 7 X (49) play with one toy or object for 5-10
minutes? 49. ____

1 2 3 4 5 6 7 X (50) play with one toy or object for 10 minutes or
longer? 50. ____

1 2 3 4 5 6 7 X (51) spend time just looking at
playthings? 51. ____

1 2 3 4 5 6 7 X (52) repeat the same sounds over and over
again? 52. ____

1 2 3 4 5 6 7 X (53) laugh aloud in
play? 53. ____

1 2 3 4 5 6 7 X (54) repeat the same movement with an object for 2
minutes 54. ____

or longer (e.g., putting a block in a cup, kicking
or hitting a mobile)?

1 2 3 4 5 6 7 X (55) pay attention to your reading during most of the
story 55. ____

when looking at picture books?

1 2 3 4 5 6 7 X (56) smile or laugh after accomplishing something (e.g.,
56. ____

stacking blocks, etc.)?

1 2 3 4 5 6 7 X (57) smile or laugh when given a
toy? 57. ____

1 2 3 4 5 6 7 X (58) smile or laugh when
tickled? 58. ____

How often during the last week did the baby enjoy:

1 2 3 4 5 6 7 X (59) being sung
to? 59. ____

1 2 3 4 5 6 7 X (60) being read
to? 60. ____

1 2 3 4 5 6 7 X (61) hearing the sound of words, as in nursery
rhymes? 61. ____

- 1 2 3 4 5 6 7 X (62) looking at picture
books? 62. ____
- 1 2 3 4 5 6 7 X (63) gentle rhythmic activities, such as rocking or
swaying? 63. ____
- 1 2 3 4 5 6 7 X (64) lying quietly and examining his/her fingers or
toes? 64. ____
- 1 2 3 4 5 6 7 X (65) being tickled by you or someone else in your
family? 65. ____
- 1 2 3 4 5 6 7 X (66) being involved in rambunctious
play? 66. ____
- 1 2 3 4 5 6 7 X (67) watching while you, or another adult, playfully
made faces? 67. ____
- 1 2 3 4 5 6 7 X (68) touching or lying next to stuffed
animals? 68. ____
- 1 2 3 4 5 6 7 X (69) the feel of soft
blankets ? 69. ____
- 1 2 3 4 5 6 7 X (70) being rolled up in a warm
blanket? 70. ____
- 1 2 3 4 5 6 7 X (71) listening to a musical toy in a
crib? 71. ____

Office Only

When playing quietly with one of her/his favorite toys, how often did your baby:

1 2 3 4 5 6 7 X (72) show
pleasure? 72. ____

1 2 3 4 5 6 7 X (73) enjoy lying in the crib for more than 5
minutes? 73. ____

1 2 3 4 5 6 7 X (74) enjoy lying in the crib for more than 10
minutes? 74. ____

When something the baby was playing with had to be removed, how often did s/he:

1 2 3 4 5 6 7 X (75) cry or show distress for a
time? 75. ____

1 2 3 4 5 6 7 X (76) seem not
bothered? 76. ____

When tossed around playfully how often did the baby:

1 2 3 4 5 6 7 X (77)
smile? 77. ____

1 2 3 4 5 6 7 X (78)
laugh? 78. ____

During a peekaboo game, how often did the baby:

1 2 3 4 5 6 7 X (79)
smile? 79. ____

1 2 3 4 5 6 7 X (80)
laugh? 80. ____

How often did your baby enjoy bouncing up and down:

1 2 3 4 5 6 7 X (81) while on your
lap? 81. ____

1 2 3 4 5 6 7 X (82) on an object, such as a bed, bouncer chair, or
toy? 82. ____

How often did the infant look up from playing:

1 2 3 4 5 6 7 X (83) when the telephone
rang? 83. ____

1 2 3 4 5 6 7 X (84) when s/he heard voices in the next
room? 84. ____

When your baby saw a toy s/he wanted, how often did s/he:

1 2 3 4 5 6 7 X (85) get very excited about getting
it? 85. ____

1 2 3 4 5 6 7 X (86) immediately go after
it? 86. ____

When given a new toy, how often did your baby:

1 2 3 4 5 6 7 X (87) get very excited about getting
it? 87. ____

1 2 3 4 5 6 7 X (88) immediately go after
it? 88. ____

1 2 3 4 5 6 7 X (89) seem not to get very excited about
it? 89. ____

Daily Activities

How often during the last week did the baby:

1 2 3 4 5 6 7 X (90) cry or show distress at a change in
parents' 90. ____
appearance, (glasses off, shower cap on, etc.)?

1 2 3 4 5 6 7 X (91) when in a position to see the television
set, 91. ____
look at it for 2 to 5 minutes at a time?

How often during the last week did the baby:

1 2 3 4 5 6 7 X (92) when in a position to see the television set, 92. ____

look at it for 5 minutes or longer?

1 2 3 4 5 6 7 X (93) protest being placed in a confining place (infant 93. ____

seat, play pen, car seat, etc)?

1 2 3 4 5 6 7 X (94) startle at a sudden change in body position (for 94. ____

example, when moved suddenly)?

1 2 3 4 5 6 7 X (95) appear to listen to even very quiet sounds? 95. ____

1 2 3 4 5 6 7 X (96) attend to sights or sounds when outdoors (for example, wind 96. ____

chimes or water sprinklers)?

1 2 3 4 5 6 7 X (97) move quickly toward new objects? 97. ____

1 2 3 4 5 6 7 X (98) show a strong desire for something s/he wanted? 98. ____

1 2 3 4 5 6 7 X (99) startle to a loud or sudden noise? 99. ____

1 2 3 4 5 6 7 X (100) look at children playing in the park or on the 100. ____

playground for 5 minutes or longer?

1 2 3 4 5 6 7 X (101) watch adults performing household activities 101. ____

(e.g., cooking, etc.) for more than 5 minutes?

1 2 3 4 5 6 7 X (102) squeal or shout when excited? 102. ____

1 2 3 4 5 6 7 X (103) imitate the sounds you made? 103. ____

1 2 3 4 5 6 7 X (104) seem excited when you or other adults acted in an 104. ____

excited manner around him/her?

When being held, how often did the baby:

1 2 3 4 5 6 7 X (105) pull away or kick? 105. ____

1 2 3 4 5 6 7 X (106) seem to enjoy him/herself? 106. ____

1 2 3 4 5 6 7 X (107) mold to your body? 107. ____

1 2 3 4 5 6 7 X (108) squirm? 108. ____

When placed on his/her back, how often did the baby:

1 2 3 4 5 6 7 X (109) fuss or protest? 109. ____

1 2 3 4 5 6 7 X (110) smile or laugh? 110. ____

1 2 3 4 5 6 7 X (111) wave arms and kick? 111. ____

1 2 3 4 5 6 7 X (112) squirm and/or turn body? 112. ____

When the baby wanted something, how often did s/he:

1 2 3 4 5 6 7 X (113) become upset when s/he could not get what s/he wanted? 113. ____

1 2 3 4 5 6 7 X (114) have tantrums (crying, screaming, face red, etc.) 114. ____

when s/he did not get what s/he wanted?

When placed in an infant seat or car seat, how often did the baby:

1 2 3 4 5 6 7 X (115) wave arms and kick? 115. ____

1 2 3 4 5 6 7 X (116) squirm and turn body? 116. ____

1 2 3 4 5 6 7 X (117) lie or sit quietly? 117. ____

1 2 3 4 5 6 7 X (118) show distress at first; then quiet down? 118. ____

Office Only

When frustrated with something, how often did your baby:

1 2 3 4 5 6 7 X (119) calm down within 5 minutes? 119. ____

When your baby was upset about something, how often did s/he:

1 2 3 4 5 6 7 X (120) stay upset for up to 10 minutes or longer? 120. ____

1 2 3 4 5 6 7 X (121) stay upset for up to 20 minutes or longer? 121. ____

1 2 3 4 5 6 7 X (122) soothe her/himself with other things (such as a stuffed 122. ____

animal, or blanket)?

When rocked or hugged, in the last week, how often did your baby:

1 2 3 4 5 6 7 X (123) seem to enjoy her/himself? 123. ____

1 2 3 4 5 6 7 X (124) seemed eager to get away? 124. ____

1 2 3 4 5 6 7 X (125) make protesting noises? 125. ____

When reuniting after having been away during the last week how often did the baby:

1 2 3 4 5 6 7 X (126) seem to enjoy being held? 126. ____

1 2 3 4 5 6 7 X (127) show interest in being close, but resisted being held? 127. ____

1 2 3 4 5 6 7 X (128) show distress at being held? 128. ____

When being carried, in the last week, how often did your baby:

1 2 3 4 5 6 7 X (129) seem to enjoy him/herself? 129. ____

1 2 3 4 5 6 7 X (130) push against you until put down? 130. ____

While sitting in your lap:

1 2 3 4 5 6 7 X (131) how often did your baby seem to enjoy her/himself? 131. ____

1 2 3 4 5 6 7 X (132) how often would the baby not be content without moving around? 132. ____

How often did your baby notice:

1 2 3 4 5 6 7 X (133) low-pitched noises, air conditioner, heating system, or refrigerator running or starting up? 133. ____

1 2 3 4 5 6 7 X (134) sirens from fire trucks or ambulances at a distance? 134. ____

1 2 3 4 5 6 7 X (135) a change in room temperature? 135. ____

1 2 3 4 5 6 7 X (136) a change in light when a cloud passed over the sun? 136. ____

1 2 3 4 5 6 7 X (137) sound of an airplane passing overhead? 137. ____

1 2 3 4 5 6 7 X (138) a bird or a squirrel up in a tree? 138. ____

1 2 3 4 5 6 7 X (139) fabrics with scratchy texture (e.g., wool)? 139. ____

When tired, how often was your baby:

1 2 3 4 5 6 7 X (140) likely to cry? 140. ____

1 2 3 4 5 6 7 X (141) show distress? 141. ____

Office Only

At the end of an exciting day, how often did your baby:

1 2 3 4 5 6 7 X (142) become
tearful? 142. ____

1 2 3 4 5 6 7 X (143) show
distress? 143. ____

For no apparent reason, how often did your baby:

1 2 3 4 5 6 7 X (144) appear
sad? 144. ____

1 2 3 4 5 6 7 X (145) seem unresponsive?
145. ____

How often did your baby make talking sounds when:

1 2 3 4 5 6 7 X (146) riding in a
car? 146. ____

1 2 3 4 5 6 7 X (147) riding in a shopping
cart? 147. ____

1 2 3 4 5 6 7 X (148) you talked to her/
him? 148. ____

Two Week Time Span

When you returned from having been away and the baby was awake, how often did s/he:

1 2 3 4 5 6 7 X (149) smile or
laugh? 149. ____

When introduced to an unfamiliar adult, how often did the baby:

1 2 3 4 5 6 7 X (150) cling to a
parent? 150. ____

1 2 3 4 5 6 7 X (151) refuse to go to the unfamiliar
person? 151. ____

1 2 3 4 5 6 7 X (152) hang back from the
adult? 152. ____

1 2 3 4 5 6 7 X (153) never "warm up" to the unfamiliar
adult? 153. ____

When in the presence of several unfamiliar adults, how often did the baby:

1 2 3 4 5 6 7 X (154) cling to a
parent? 154. ____

1 2 3 4 5 6 7 X (155)
cry? 155. ____

1 2 3 4 5 6 7 X (156) continue to be upset for 10 minutes or
longer? 156. ____

When visiting a new place, how often did the baby:

1 2 3 4 5 6 7 X (157) show distress for the first few minutes? 157. ____

1 2 3 4 5 6 7 X (158) continue to be upset for 10 minutes or more? 158. ____

1 2 3 4 5 6 7 X (159) get excited about exploring new surroundings? 159. ____

1 2 3 4 5 6 7 X (160) move about actively when s/he is exploring new surroundings? 160. ____

When your baby was approached by an unfamiliar person when you and s/he were out (for example, shopping), how often did the baby:

1 2 3 4 5 6 7 X (161) show distress? 161. ____

1 2 3 4 5 6 7 X (162) cry? 162. ____

Only

When an unfamiliar adult came to your home or apartment, how often did your baby:

1 2 3 4 5 6 7 X (163) allow her/himself to be picked up without protest? 163. ____

1 2 3 4 5 6 7 X (164) cry when the visitor attempted to pick her/him up? 164. ____

When in a crowd of people, how often did the baby:

1 2 3 4 5 6 7 X (165) seem to enjoy him/herself? 165. ____

Did the baby seem sad when:

1 2 3 4 5 6 7 X (166) caregiver is gone for an unusually long period of time? 166. ____

1 2 3 4 5 6 7 X (167) left alone/unattended in a crib or a playpen for an 167. ____
extended period of time?When you were busy with another activity, and your baby was not able to get your attention, how often did s/he:

1 2 3 4 5 6 7 X (168) become sad? 168. ____

1 2 3 4 5 6 7 X (169) cry? 169. ____

When your baby saw another baby crying, how often did s/he:

1 2 3 4 5 6 7 X (170) become tearful? 170. ____

1 2 3 4 5 6 7 X (171) show distress? 171. ____

When familiar relatives/friends came to visit, how often did your baby:

1 2 3 4 5 6 7 X (172) get excited? 172. ____

1 2 3 4 5 6 7 X (173) seem indifferent? 173. ____

Soothing Techniques

Have you tried any of the following soothing techniques in the last two weeks? If so, how quickly did your baby soothe using each of these techniques? Circle (X) if you did not try the technique during the LAST TWO WEEKS.

When rocking your baby, how often did s/he:

1 2 3 4 5 6 7 X (174) soothe immediately? 174. ____

1 2 3 4 5 6 7 X (175) not soothe immediately, but in the first two minutes? 175. ____

1 2 3 4 5 6 7 X (176) take more than 10 minutes to soothe? 176. ____

When singing or talking to your baby, how often did s/he:

1 2 3 4 5 6 7 X (177) soothe immediately? 177. ____

1 2 3 4 5 6 7 X (178) not soothe immediately, but in the first two minutes? 178. ____

1 2 3 4 5 6 7 X (179) take more than 10 minutes to soothe? 179. ____

When walking with the baby, how often did s/he:

1 2 3 4 5 6 7 X (180) soothe immediately? 180. ____

1 2 3 4 5 6 7 X (181) not soothe immediately, but in the first two minutes? 181. ____

1 2 3 4 5 6 7 X (182) take more than 10 minutes to soothe? 182. ____

When giving him/her a toy, how often did the baby:

1 2 3 4 5 6 7 X (183) soothe immediately? 183. ____

1 2 3 4 5 6 7 X (184) not soothe immediately, but in the first two minutes? 184. ____

1 2 3 4 5 6 7 X (185) take more than 10 minutes to soothe? 185. ____

When showing the baby something to look at, how often did s/he:

1 2 3 4 5 6 7 X (186) soothe immediately? 186. ____

1 2 3 4 5 6 7 X (187) not soothe immediately, but in the first two minutes? 187. ____

1 2 3 4 5 6 7 X (188) take more than 10 minutes to soothe? 188. ____

When patting or gently rubbing some part of the baby's body, how often did s/he:

1 2 3 4 5 6 7 X (189) soothe immediately? 189. ____

1 2 3 4 5 6 7 X (190) not soothe immediately, but in the first two minutes? 190. ____

1 2 3 4 5 6 7 X (191) take more than 10 minutes to soothe? 191. ____

Appendix F – CSBS Caregiver Questionnaire

40. Which of these actions have you seen your child do?

- take blocks out of container
- put blocks in container
- build a tower of blocks
- put puzzle pieces together
- stack rings on ring stacker without regard for order
- put rings on ring stacker in order
- hold crayon or marker and scribble on paper
- draw shapes or patterns on paper
- squeeze and bang playdough
- make shapes with playdough, such as hot dogs or pancakes

41. Which of these actions have you seen your child do with books?

- turn pages
- look at pictures
- look at pictures and then look at you
- point to pictures without being asked
- point to pictures when asked
- label pictures

Additional comments

42. How has your child's communication changed over the past few months?

43. List a few strengths or assets you observe in your child.

44. List any concerns you have about your child's development.

45. Is there anything else about your child that you think is important to share with us?

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Gestures

19. Does your child use gestures that are easily understood by others, such as giving objects, showing objects, pointing, and waving?

Not yet Sometimes Often

20. Which of the following gestures have you seen your child use?

- give an object to you
- show an object to you (i.e., by extending arm but not releasing object)
- push an object away
- raise arms to be picked up
- reach with an open hand toward an object
- wave "hi" or "bye bye"
- points to an object or a picture that is within reach
- point to an object or a picture out of reach
- shake head to indicate "no"
- nod head to indicate "yes"

Sounds

21. Does your child use sounds to communicate both pleasure and discomfort?

Not yet Sometimes Often

22. Children use sounds to communicate in vocal play before they use sounds in words. Does your child use a variety of different consonant sounds, such as "ba," "ga," "la," and "da," either in vocal play or in words?

Not yet Sometimes Often

23. If so, which of the following sounds have you heard your child use, either in vocal play or in words?

<input type="checkbox"/> /m/ as in "mamamama" or "mama" or "moo"	<input type="checkbox"/> /w/ as in "woowoo" or "weewee" or "wagon"
<input type="checkbox"/> /r/ as in "rumamum" or "no no"	<input type="checkbox"/> /l/ as in "lalala" or "balloon" or "litter"
<input type="checkbox"/> /b/ as in "babababa" or "bibo" or "bye bye"	<input type="checkbox"/> /j/ as in "yayaya" or "yum yum" or "you"
<input type="checkbox"/> /d/ as in "dadododo" or "daddy"	<input type="checkbox"/> /s/ as in "sasasa" or "sock" or "kiss"
<input type="checkbox"/> /g/ as in "googoo" or "gone gone"	<input type="checkbox"/> /sh/ as in "shashasha" or "hush" or "shoe"

Words

24. Does your child put sounds together, either in vocal play or words (for example, "baba," "mamama," "dada," "bye bye")?

Not yet Sometimes Often

25. Does your child use words to communicate that are understandable to you?

Not yet Sometimes Often

26. If so, which of the following words have you heard your child use (include approximations that you recognize, such as "mama" for banana or "baba" for bottle)?

<input type="checkbox"/> mommy	<input type="checkbox"/> moo	<input type="checkbox"/> night night	<input type="checkbox"/> bath	<input type="checkbox"/> Others (optional):
<input type="checkbox"/> daddy	<input type="checkbox"/> woof	<input type="checkbox"/> outside	<input type="checkbox"/> book	
<input type="checkbox"/> baby	<input type="checkbox"/> gr (animal noise)	<input type="checkbox"/> yum yum	<input type="checkbox"/> car	
<input type="checkbox"/> dog	<input type="checkbox"/> peekaboo	<input type="checkbox"/> ursoom	<input type="checkbox"/> cookie	
<input type="checkbox"/> kitty	<input type="checkbox"/> bye bye	<input type="checkbox"/> ouch	<input type="checkbox"/> juice	
<input type="checkbox"/> bird	<input type="checkbox"/> no	<input type="checkbox"/> up	<input type="checkbox"/> milk	
<input type="checkbox"/> duck	<input type="checkbox"/> no	<input type="checkbox"/> bottle	<input type="checkbox"/> eyes	
<input type="checkbox"/> eye	<input type="checkbox"/> all gone	<input type="checkbox"/> banana	<input type="checkbox"/> balloon	
<input type="checkbox"/> nose	<input type="checkbox"/> uh oh	<input type="checkbox"/> ball	<input type="checkbox"/> truck	

27. Does your child use words that are understandable to unfamiliar adults?

Not yet Sometimes Often

28. Does your child put two or more words together (for example, more cookies, daddy car, bye bye kitty)?

Not yet Sometimes Often

CSBS DP Caregiver Questionnaire

Child's name: _____ Date of birth: _____ Date filled out: _____

Was born premature? _____ If yes, how many weeks premature? _____

Filled out by: _____ Relationship to child: _____

Instructions for caregivers: The following questions are about how your child communicates and plays. The questions have to do with how your child expresses him- or herself using actions, gestures, sounds, or words. We would like you to fill this out over a weekend or at a time when you can observe your child and notice the behaviors listed. Please check all the choices that best describe your child's behavior. If you are not sure, please choose the closest response based on your experience. Children at your child's age are not necessarily expected to be able to do all the behaviors listed.

Emotion and Eye Gaze

- When your child is happy, does he/she smile or laugh and look at you at the same time? Not yet Sometimes Often
- When your child is playing with a toy, does he/she look at you and then back at the toy? Not yet Sometimes Often
- If you look at and point to a toy out of your child's reach, does your child look at the toy? Not yet Sometimes Often
- When your child is upset or frustrated, does he/she express this clearly with facial expression, sounds, or words? Not yet Sometimes Often
- How often does your child get upset or frustrated each day? Rarely Sometimes Often
- When your child is upset, does he/she calm down easily (within a few minutes)? Rarely Sometimes Usually
- When you are with your child, is your child comfortable interacting with unfamiliar people or new situations? Rarely Sometimes Usually
- When your child is afraid, does he/she seek comfort from you? Not yet Sometimes Often

Communication

- Does your child clearly let you know what he/she needs help (for example, wants you to open a container)? Not yet Sometimes Often
- Does your child clearly let you know when he/she wants an object that is out of reach? Not yet Sometimes Often
- Does your child let you know that he/she does not want something that you are offering him/her? Not yet Sometimes Often
- Does your child greet you when you come in the room or leave? Not yet Sometimes Often
- Does your child reach out to give you a hug or kiss? Not yet Sometimes Often
- Does your child try to get your attention when you are busy doing something, such as when you are talking with an adult or preparing a meal? Not yet Sometimes Often
- If your child does something that is funny and you laugh, does your child do it again for the attention? Not yet Sometimes Often
- Does your child try to get you to notice interesting objects, not to get you to do anything with them, but just to get you to look at them (for example, show you an object or point to a picture in a book)? Not yet Sometimes Often
- Does your child try to draw your attention to exciting or unexpected things, such as a pop-up toy or something falling down? Not yet Sometimes Often
- If you can't figure out what your child is trying to communicate, does your child try again or use a different way to get his/her meaning across? Not yet Sometimes Often

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Understanding

29. Does your child respond when you call his/her name (for example, by looking/turning head)?

Not yet Sometimes Often

30. Does your child respond appropriately to gestures (for example, giving you an object when you say "give it to me" while holding out your hand or while pointing to the object)?

Not yet Sometimes Often

31. Does your child understand words or short phrases when you use only words and do not use gestures?

Not yet Sometimes Often

32. If so, which of the following words does your child understand without gestures (i.e., if you say the word, your child will find the object or carry out the action)?

<input type="checkbox"/> mommy	<input type="checkbox"/> tummy	<input type="checkbox"/> night night	<input type="checkbox"/> book	<input type="checkbox"/> Others (optional):
<input type="checkbox"/> daddy	<input type="checkbox"/> foot	<input type="checkbox"/> outside	<input type="checkbox"/> diaper	
<input type="checkbox"/> child's name	<input type="checkbox"/> hair	<input type="checkbox"/> hat	<input type="checkbox"/> car	
<input type="checkbox"/> baby	<input type="checkbox"/> peekaboo	<input type="checkbox"/> drink	<input type="checkbox"/> juice	
<input type="checkbox"/> dog	<input type="checkbox"/> bye bye	<input type="checkbox"/> hug	<input type="checkbox"/> shoe	
<input type="checkbox"/> kitty	<input type="checkbox"/> no	<input type="checkbox"/> bite	<input type="checkbox"/> cup	
<input type="checkbox"/> bird	<input type="checkbox"/> hi	<input type="checkbox"/> bottle	<input type="checkbox"/> keys	
<input type="checkbox"/> nose	<input type="checkbox"/> all gone	<input type="checkbox"/> bath	<input type="checkbox"/> balloon	
<input type="checkbox"/> eyes	<input type="checkbox"/> uh oh	<input type="checkbox"/> ball	<input type="checkbox"/> trucks	

Object Use

33. Does your child show interest in playing with a variety of objects?

Not yet Sometimes Often

34. Does your child use a variety of common objects appropriately (for example, spoon, spoon, toothbrush)?

Not yet Sometimes Often

35. If so, which of the following actions have you seen your child do with objects?

<input type="checkbox"/> drink with a cup or bottle	<input type="checkbox"/> brush teeth
<input type="checkbox"/> comb or brush hair	<input type="checkbox"/> wash or wipe face with cloth
<input type="checkbox"/> feed self with a spoon	<input type="checkbox"/> roll or throw a ball
<input type="checkbox"/> stir with a spoon	<input type="checkbox"/> push a toy vehicle
<input type="checkbox"/> pour with cup or bowl	<input type="checkbox"/> put toy telephone to ear

36. Does your child pretend to play with toys (for example, feed a stuffed animal, put a baby doll to sleep, get an animal figure in a vehicle)?

Not yet Sometimes Often

37. If so, which of the following actions have you seen your child do when playing with another person, a stuffed animal, or a doll?

<input type="checkbox"/> feed with a spoon	<input type="checkbox"/> wash or wipe face with cloth
<input type="checkbox"/> drink with a cup or bottle	<input type="checkbox"/> brush teeth with toothbrush
<input type="checkbox"/> comb or brush hair	<input type="checkbox"/> put on diaper
<input type="checkbox"/> cover with blanket	<input type="checkbox"/> hug or kiss

38. Does your child pretend by putting two or more actions together in a sequence, such as stirring food and feeding doll or washing doll's face and covering doll with a blanket?

Not yet Sometimes Often

39. Does your child build or arrange toy objects (for example, build a tower of blocks, stack rings, put puzzle pieces together)?

Not yet Sometimes Often

Appendix J – CSBS Caregiver Perception Rating

DAY



CSBS DP Behavior Sample: Caregiver Perception Rating

Child's name: _____ Date of birth: _____ Date filled out: _____

Filled out by: _____ Relationship to child: _____

Instructions for caregivers: Please compare your child's behavior during the communication and play assessments we have just completed to your observations of your child in similar situations. Circle the response that comes closest to your observations.

	1	2	3
1. Alertness	less than usual/sleepy	typical	very alert/ greater than usual
2. Emotional reaction	more negative than usual	typical	more positive than usual
3. Level of interest and attention	less interest than usual	typical	greater interest/ greater attention
4. Comfort level	more cautious/ more wary than usual	typical	more comfortable/ relaxed than usual
5. Level of activity	less active than usual	typical	more active than usual
6. Overall level of communication	less than usual	typical	greater than usual
7. Play behavior	less organized and less focused	typical	more organized and focused
Comments: _____			

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Appendix A.2 – IRB Addendum 10/01/2010

1) State what is being proposed and where in the protocol and/or consent what was changed.

We are proposing the addition of several members to the research team and some increase to the scope of advertisement. Also, the script to be used during data collection has been modified to accurately reflect the procedure we will be following based on feedback from pilot testing.

Add co-PI: Rebecca Landa, Ph.D., 

Add co-investigators: Eileen Chai, Jillian Chavis, Kevin Chodnicki, Timothy Crisci, Nathan Destler, Duncan Graham, Kesshi Jordan, Richard Landa, Conrad Merkle, Soh Park, Chris Paxton, Rachita Sood, James Tanner

Changes in IRB Initial Application:

2a) We will be hanging flyers around campus and in pediatric offices that agree within a 25 mile radius of College Park.

3) We will change the procedure so that the infant is prepared for motion capture before performing the object exploration task. Several articles of clothing, hereafter referred to as the motion capture suit, including a cap, bib, and Velcro straps with 5mm spherical markers securely attached will be put on the infant. Also, color video will be taken rather than grayscale, as was previously proposed.

Appendix I, the protocol for the mocap session, has been revised based on feedback from a pilot session.

2) Provide the rationale/justification for the change.

We will be working closely with Dr. Landa for recruitment of high-risk infants and scheduling infants. Each one of the students/co-investigators is a part of the research team.

We are expanding the scope of advertisement in order to attract more participants.

By putting the motion capture suit on before the object exploration task, the infant will be able to acclimate him or herself to having the extra clothing.

By revising based on feedback, we improved the script by making it smoother and more easily understood.

3) State what impact the change has on risks to participants. Please state the number of currently enrolled participants and if the change in risk will require re-consent. If the changes will not require re-consent, please state why.

The proposed changes will have no impact on risks to participants. There are no currently scheduled participants, so no one will have to re-consent in order to participate.

4) State whether the change has an impact on the scientific integrity of the study, (i.e. decreases, increases, no impact).

No impact.

5) List the documents included with the application that have been modified (consent forms, flyers, data collection forms, surveys). State what has been changed in each modified document.

Appendix I-Protocol for mocap session

Based on a pilot session, we have modified this document heavily, so it is included as a separate document.

Observation sheet- We have created an observation sheet to streamline our data analysis by putting all of the information useful for analysis in one document without identifying information so it can be kept at the University of Maryland.

Appendix A.3 – IRB Addendum 11/15/2010

1) State what is being proposed and where in the protocol and/or consent what was changed.

We are proposing modifications to several documents.

Changes in IRB Initial Application:

2a) The compensation will be changed to 20 dollars per participant.

2b) Participant's older siblings will no longer be assessed using the SCQ (Appendix B). If an older sibling has any evaluations leading to a diagnosis of ASD, they will be referred to Dr. Landa, who will perform tests that have been approved by Johns Hopkins IRB Review Board to confirm the diagnosis. Our exclusion based on birth weight has been changed to 2500g.

2d) Compensation will be changed to \$20 per participant.

3) The eligibility screening for low-risk participants will consist of the telephone screening interview (TSI; Appendix C). Eligibility screening for high-risk participants will consist of the TSI and various tests Dr. Landa will perform to confirm the diagnosis of the proband. We will no longer be measuring the infant's height, weight, and head circumference. The infant object exploration task will not contain the task dealing with imitation that was initially proposed. We will have the infants perform several more tasks based on a more thorough review of the literature and suggestions from Dr. Landa. While assessing visual tracking, an object is moved across the infant's field of vision while his or her head is tracked. Postural control is determined by presenting the infant with similar toys with varying mass to study his or her stability and posture.

4) Trained researchers will not be able to come from Kennedy Krieger to attend every testing session, so members of the research team who have been trained in the infant object exploration task will be conducting the session.

5) Transportation of the participant's information to and from Kennedy Krieger has been deemed unnecessary, so we will keep all of the documents in locked cabinets in the Keck Laboratory for convenience. Also, files containing personal information will not be stored on Kennedy Krieger computers, but rather on password-protected computers in the Keck Laboratory. Any motion capture files that are moved from these computers will only contain deidentified information such as participant ID.

Appendix G – Consent form

We have added the phrase, "in collaboration with Rebecca Landa, Ph.D., CCC-SLP of the Kennedy Krieger Institute in Baltimore" to reflect her addition as co-PI. Additional changes reflect changes made in the procedure and other documents, such as addition of tasks.

Appendix H – HIPAA Privacy Authorization Form

The UMD privacy officer will be contacted if a participant is to revoke their authorization, as opposed to the Johns Hopkins privacy officer.

2) Provide the rationale/justification for the change.

3) Compensation has been changed to \$20 per participant because our budget has expanded to allow greater compensation with the expected number of participants. The SCQ was considered to not be as confirmatory as Dr. Landa's screening. The birth weight was incorrectly transcribed in the original application. The eligibility screening was cut down to reduce the time commitment on low-risk participants. Based on a more thorough literature review and recommendations from Dr. Landa, procedures have been taken out and tasks added. The logistics of researchers traveling to the University of Maryland and transporting all forms and databased information to Kennedy Krieger was considered difficult to manage and so was changed.

Advertisement contact information was changed to that of the research team at UMD to accommodate the audience we are advertising for around campus.

The TSI has been changed to reduce the time requirement to complete it.

The HIPAA privacy officer was changed because the research is mostly being conducted at the University of Maryland.

The consent form, motion capture script, and observation sheet were updated to reflect all of these changes.

3) State what impact the change has on risks to participants. Please state the number of currently enrolled participants and if the change in risk will require re-consent. If the changes will not require re-consent, please state why.

The proposed changes will have no impact on risks to participants. There are no currently scheduled participants, so no one will have to re-consent in order to participate.

4) State whether the change has an impact on the scientific integrity of the study, (i.e. decreases, increases, no impact).

No impact.

5) List the documents included with the application that have been modified (consent forms, flyers, data collection forms, surveys). State what has been changed in each modified document.

Appendix A – Advertisement

Under benefits, the amount of compensation has been changed to \$20. The contact information has been changed.

Appendix C – TSI

This has been revised to assess eligibility of infants based on the exclusionary principles listed in the initial application. Also, Appendix D, the Intake Questionnaire, has been merged with this document.

Appendix G – Consent form

We have added the phrase, “in collaboration with Rebecca Landa, Ph.D., CCC-SLP of the Kennedy Krieger Institute in Baltimore” to reflect her addition as co-PI. Additional changes reflect changes made in the procedure and other documents, such as addition of tasks.

Appendix H – HIPAA Privacy Authorization Form

The UMD privacy officer will be contacted if a participant is to revoke their authorization, as opposed to the Johns Hopkins privacy officer.

Appendix I, the protocol for the mocap session, has been revised to add the new tasks.

The observation sheet has also been updated to reflect the addition of tasks.

SEEKING VOLUNTEERS FOR RESEARCH STUDY

WHAT IS THE STUDY ABOUT?

This research is being done to determine how motor development differs for children at risk for autism and those who are not at risk.



WHAT IS INVOLVED?

If eligible, you and your child will come to the

University of Maryland, College Park for one testing session which will take approximately one hour.

Children 6–12 months old with or without a family history of autism spectrum disorder may join.

- Your child will be guided through several tasks in order for us to track his/her movements. Before these tasks, a suit with reflective markers will be placed on your child. These markers allow our motion capture system to track your child's movements.
- Parents will be asked to complete questionnaires.

WHAT ARE THE BENEFITS OF PARTICIPATING?

- There are no direct health benefits for you or your child, but your participation may help others in the future.
- You will be given \$20 for your participation.

WHAT ARE THE RISKS?

- There are no significant risks associated with participation.

CONTACT US!

If you are interested in volunteering for this study please contact us to find out more:

Phone: [REDACTED]
e-mail: [REDACTED]

Telephone Screening Interview

Hello, my name is _____ and I am calling you about the study in which you had expressed some interest, titled *Analyzing the Movement of Infants at Risk for Autism*. Your participation in this 15-minute phone call is completely voluntary. I need to ask you a few questions in order to determine whether your child and you are eligible for this research study. I will ask you general questions about your child's development and medical history. You do not have to answer any questions you do not wish to answer and you may stop at any time. Your information will only be seen by researchers involved in the study, including researchers from the University of Maryland and Kennedy Krieger Institute. Your answers will be confidential. No one will know the answers except for the research team. If your child does not qualify for the study we will destroy the information we have. If your child does qualify for the study and you agree to participate, we will send you some questionnaires to fill out and schedule a motion capture session to take place at the University of Maryland. If you do not agree to continue the phone call, it will not affect your health care in any way.

Before I begin I would like to tell you a little bit about the research. This research is being done to determine how motor development differs for children at risk for autism and those who are not at risk. Children between 6 and 10 months of age, with or without a family history of autism spectrum disorder may join. If you agree to be in this study, you will be asked to come to the University of Maryland, College Park, to complete the motion capture session, which will last up to an hour. Your child will be guided through a series of tasks in order for us to track his or her movements. Before the session begins, a motion capture suit consisting of a hat, Velcro bands and a bib with 5mm reflective markers securely attached will be placed on your child's body. These markers will allow the camera equipment to track your child's movements. The motor-tracking portion involves several tasks: object exploration, pull-to-sit, reaching, visual tracking, and postural control.

Do you have any questions or concerns about these tasks or the motion capture suit? *If so, refer to the following descriptions:*

1.) Object exploration: Your child is given the opportunity to play with a set of toys while researchers observe. 2.) Pull-to-sit: the tester will hold your child's hands and lift him/her into a sitting position from a lying position. 3.) Reaching: the tester will place your child in a lying position. The tester will then hold a toy above your child to see if he or she reaches for it. 4.) Visual tracking: an object is moved across the infant's field of vision while his or her head is tracked. 5.) Postural control: your

child will be presented with similar toys with varying mass to study his or her stability and posture.

The potential risks associated with this study are no more than minimal. One risk involves a potential loss of your confidentiality. We will take all possible steps to maintain confidentiality. If you or your child gets tired during a test, we will take a break or stop. We will be as flexible as possible in scheduling appointments. Some people may also be uncomfortable being videotaped, or answering personal questions. You do not have to answer any questions that you are not comfortable with. You are free to ask questions or withdraw at any time during the study.

There are no direct health benefits for you or your child. However, taking part in this study may help others in the future. The knowledge gained from this study may enable the public to better understand autism spectrum disorders.

You do not have to join this study. The study procedures will be provided at no cost to you. However, families will be responsible for the costs of transportation to and from the University of Maryland, College Park. You will be given \$20 for your participation.

Do you have any questions?

Do you think you would like to take part in this research?

[if no, thank the person and hang up]

[if yes, continue with the screening.]

Ascertainment Date: _____

1.) How did you hear about us?

Primary Ascertainment Source: *CHECK ONE*

School		CARD		Friend	
Physician		Other			

Additional Info: _____

2.) I would like to ask questions about each member in your family such as their birthdates, genders, and relationships to each other.

Do you have an older child? Yes No

IF YES, does this child have a history of autism? Yes No

***NOTE: ALL LOW RISK PARTICIPANTS MUST HAVE NO OLDER SIBLINGS WITH AUTISM.**

Ask questions to fill out the table.

Ineligibility criteria from above table:

- Child is between 6 and 10 months
- Child is adopted or foster child
- Child's birth weight was less than 5.5 pounds (2500g)
- Child's gestational week is less than or equal to 36 weeks

If not eligible, then go to appropriate closure section.

6.) Were any of your children conceived using IVF methods? YES NO

7.) May I get (or confirm) your address?

Street:

City/State/ZIP:

8.) May I get (or confirm) your phone number? Is there any other number at which we can reach you? What is the best time of day to call you (and at which number)?

Home:

Cell:

Work:

Pager:

Mother's workplace address: _____

Mother's workplace phone number: _____

Father's workplace address: _____

Father's workplace phone number: _____

9.)What is the highest level of education [you/your spouse] completed? What is [your/your spouse's] current occupation? To determine Hollingshead SES, which is required for reporting.

Mother's Education:

Mother's Occupation:

Father's Education:

Father's Occupation:

10.)With which ethnicity would your children best identify? Check one box: Required for reporting.

Asian	
Black or African American	
Bi- or multiracial (<i>please specify</i>): _____	
American Indian/Alaskan Native	
Native Hawaiian or other Pacific Islander	
White	
Other (<i>please specify</i>): _____	
Unknown or Not reported	

Do you consider your children to be Latino or Hispanic? Yes No Required for reporting.

Does anyone on either side of your family (aunts, uncles, cousins) have an Autism Spectrum Disorder or suspicion of? YES NO

If yes, what is the relation and what is the diagnosis?

OTHER EXCLUSIONARY CRITERIA

If there is a potential issue in this section, try to get as many details as possible, continue to End Point C and then skip to the closure section.

10.) Now I am going to ask you about some general questions about {CHILD'S} medical history. Ask for proband (if applicable) and non-proband.

Exclusionary Criteria: Exclude if YES, unless otherwise stated.	Proband	Non Proband
--	----------------	--------------------

Vision Impairment (not within normal limits with correction)	Not exclusionary	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Hearing Impairment (not within normal limits with correction)	Not exclusionary	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
PKU (Phenylketonuria)	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Congenital Rubella (German measles)	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Neurofibromatosis	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Tuberous Sclerosis	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Fragile X	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Velo-Cardio Facial Syndrome	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
<i>IF NO or DK, ask about the following two conditions:</i>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/>
Congenital heart defect IF YES: Please explain _____		DK <input type="checkbox"/>
Cleft Palate	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
<i>If congenital heart defect and/or cleft palate, check with KKI for eligibility.</i>		
Any falls where child lost consciousness or had any kind of severe head injury requiring treatment? A fall resulting in a loss of consciousness or other severe head injury is exclusionary for ALL except Proband	Exclusionary	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
Seizures IF YES. What type? _____ Two or more?	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/> Yes <input type="checkbox"/> No <input type="checkbox"/>
IF NO. Ever diagnosed with Infantile Spasms?	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>	Yes <input type="checkbox"/> No <input type="checkbox"/> DK <input type="checkbox"/>
<i>Seizures only exclusionary for younger sibs in Early Detection; must have >= 2 non-febrile seizures or have been diagnosed with Infantile Spasms to be excluded.</i>		

11.) Did you ever drink alcohol while you were pregnant with [name], even before you knew you were pregnant? Yes No

Exclusionary

12.) Did you ever take drugs - legal or illegal - or medications - prescribed or not prescribed by your doctor - while you were pregnant with [name], even before you knew you were pregnant?

Yes No

IF YES. What were those drugs or medications, and please let me know whether they were obtained through prescription? List drugs/medications and whether prescription (P) or non-prescription (NP):

Evidence of non-prescription illegal drug use during pregnancy will lead to ineligibility. Please make note below.

Proband: Yes No DK Non-Proband: Yes No DK

Please note that use of other drugs of medication may also lead to ineligibility.

13.) Were there any birth complications for {CHILD}? Was the child hospitalized in the Neonatal Intensive Care Unit (NICU)?

Complications: Yes / No **IF YES: Please explain** (Asphyxia? Was {child} vented? Hemorrhage?

In NICU: Yes / No **IF YES: How many days did {CHILD} stay in the NICU?** _____

What was {CHILD's} APGAR Score at 1 minute and 5 minutes? (range is 0-10)

Non-Proband 1 min: _____ Non-Proband 5 min: _____ at 5 min: <5 / ≥ 5

14.) [Now] for {CHILD}

NON-PROBAND PRIOR EVALUATIONS It is a **red flag** for any control to have had any prior evaluations! Remember to try to determine why parent/physician wanted to have evaluation.

<i>Date</i>	<i>Name/Type (MD - Specialty, Psychologist, OT, PT, SLP, etc.)/ Location of Examiner</i>	<i>Diagnosis</i>	<i>Reason for evaluation</i>

15.) Intake Questionnaire

Do you have any concerns about your child's current development? Yes No

If yes, complete the following questions:

Language/Communication: (Check all that apply)

- | | | |
|---|--|--------------------------------|
| <input type="checkbox"/> Language expression | <input type="checkbox"/> Use of communicative gestures | <input type="checkbox"/> Other |
| <input type="checkbox"/> Language comprehension | <input type="checkbox"/> Use of facial expression | |
| <input type="checkbox"/> Conversational skills | <input type="checkbox"/> Articulation/Speech | |

Please describe your concerns in the space below

Social Interaction:

(Check all that apply)

- | | | |
|---|--|--------------------------------|
| <input type="checkbox"/> Play Skills | <input type="checkbox"/> Peer social interactions | <input type="checkbox"/> Other |
| <input type="checkbox"/> Eye Contact | <input type="checkbox"/> Adult social interactions | |
| <input type="checkbox"/> Response to name | <input type="checkbox"/> Shared Interest with others | |

Please describe your concerns in the space below

Motor Skills: (Check all

that apply)

- | | | |
|---|---|--------------------------------|
| <input type="checkbox"/> Fine motor Skills | <input type="checkbox"/> Unusual gait (e.g., toe walking) | <input type="checkbox"/> Other |
| <input type="checkbox"/> Gross motor skills | <input type="checkbox"/> Clumsiness | |
| <input type="checkbox"/> Muscle tone | <input type="checkbox"/> Atypical motor features | |

Please describe your concerns in the space below

Behavior: (Check all that

apply)

- | | | |
|---|--|---|
| <input type="checkbox"/> Intense interests/preoccupations | <input type="checkbox"/> Unusual hand or body mannerisms | |
| <input type="checkbox"/> Hyperactivity | <input type="checkbox"/> Noncompliance | <input type="checkbox"/> Anxiety |
| <input type="checkbox"/> Inattention | <input type="checkbox"/> Tantrums/Meltdowns | <input type="checkbox"/> Self-injury |
| <input type="checkbox"/> Other | <input type="checkbox"/> Anxiety | <input type="checkbox"/> Depression/
Sadness |

Please describe your concerns in the space below

Sensory Issues: (Check all that apply)

- Sensory seeking behavior Sensory aversions

Sensory Modalities Affected: (Check all that apply)

- | | |
|-------------------------------------|---|
| <input type="checkbox"/> Auditory | <input type="checkbox"/> Tactile |
| <input type="checkbox"/> Visual | <input type="checkbox"/> Oral |
| <input type="checkbox"/> Vestibular | <input type="checkbox"/> Other (describe below) |

Please describe your concerns in the space below

Temperament: (Check

all that apply)

- | | |
|--|--|
| <input type="checkbox"/> Shyness | <input type="checkbox"/> Impulsiveness |
| <input type="checkbox"/> Slow to warm up | <input type="checkbox"/> Adaptability |
| <input type="checkbox"/> Cautiousness | <input type="checkbox"/> Difficulty with mood regulation |

Please describe your concerns in the space below

Feeding/GI Issues:

(Check all that apply)

- | | |
|--|---|
| <input type="checkbox"/> Restricted range of food | <input type="checkbox"/> Poor appetite |
| <input type="checkbox"/> Aversion to texture of food | <input type="checkbox"/> Special dietary issues |
| <input type="checkbox"/> Feeding problems | <input type="checkbox"/> Food allergies |

Please describe your concerns in the space below

Other: (Check all that apply)

- | | |
|--|---|
| <input type="checkbox"/> Sleep problems | <input type="checkbox"/> Bladder/Bowel control |
| <input type="checkbox"/> Hygiene issues | <input type="checkbox"/> Other (describe below) |
| <input type="checkbox"/> Daily living skills | |

Please describe your concerns in the space below

CLOSURE SECTION: Suggested script outline, but improvise as you see fit! You may wish to refer a family to the clinic if they are ineligible. Note: If the cause for ineligibility is “sensitive,” you may wish to avoid specifying it. Furthermore, you may also want to avoid specifying the cause for ineligibility if it is something that we may not want to share with potential families that may be tempted to be less than truthful.

Thank you so much for taking the time to answer my questions.

You have / have not (*circle one*) met our eligibility criteria based on the TSI.

IF ELIGIBLE:

The next step in the study will be to schedule an appointment for you to visit the Keck Laboratory. Would you like to schedule that appointment now?

Date: _____

Time: _____

IF FOUND NOT ELIGIBLE ACCORDING TO THIS TSI:

Thank you for your interest in the study and for contacting us. Unfortunately [due to _____] you do not meet eligibility criteria for this study.

IF NOT SURE OF ELIGIBILITY: At this point [based upon the information you have given me] we are unsure of your eligibility at this time. I will follow up with the research coordinator and then I will get back to you to let you know whether your family is eligible or not.

If TSI broken-off in the middle and not completed add: **If you are still eligible, we would like you to complete the remainder of this Telephone Screening Interview later.**

Thank you. If you have any further questions, feel free to contact the research team at

██████████.

FAMILY INFORMATION

ID Number _____

Ascertainment Date: _____

Eligible? Yes No Undecided

Group? High Risk (has older sib with autism) Low Risk
Control

If not eligible, why? REFUSED

UNAVAILABLE (lives too far away)

INELIGIBLE: _____

OTHER: _____

Protocol for motion capture session in Keck Laboratory

[Address parent] [Here you can give a brief introduction. Welcome the parents and thank them for agreeing to participate in our study.]

Introduction:

I will be reading from this script for the remainder of this session. This is to ensure that we minimize variability between our participant sessions. Instructions and explanations are constant between sessions. Please feel free to ask questions at any point.

1. Welcome to the Keck Laboratory for the Analysis of Visual Movement. You are here to participate in the motion capture session for the study of Infants at Risk for Autism Spectrum Disorders. At this point, you have completed eligibility screening over the telephone, as well as the questionnaires that were subsequently mailed to you. Today we will complete the motion capture portion of the study, including an infant object exploration task, a pull-to-sit, a reaching task, a visual tracking task, and a postural control task. Your child will wear a motion capture suit for the majority of this session [show parent suit]. The reflective markers are securely attached to this suit. The motion capture session will last approximately 30 minutes and will be adapted to accommodate the interest of your infant, but the researcher will initiate each task three times to record optimal data. Throughout the motion capture session, your infant will be allowed to move freely around the designated area. He/she will be allowed to explore and play with the infant-safe toys throughout the motion capture. These toys may be used to prompt the tasks, specifically the reaching, visual tracking, and postural control tasks. Do you have any questions at this point? [Answer questions and then continue reading from 2.]

2. Please read the Informed Consent and Privacy Authorization Forms [hand the parent Appendices G and H] provided and ask any questions you may have before signing if you agree to the provisions of the study. Note that each page of the informed consent form must be initialed to indicate that you have read each page, and that there is a choice on page 2 as to whether your child can be videotaped during this session. This is strictly for comparison purposes in order to verify the integrity of the data after it is collected by the motion capture system during this session. Please check whether you agree or do not agree for your child to be videotaped. [Answer any additional questions.]

[After the parent reads and signs the Informed Consent and Privacy Authorization forms, continue with 3b. If the parent decides not to sign he or she and his or her child cannot participate in the motion capture session and proceed with 3a.]

3a. Thank you for your time. Have a nice day.

3b. Thank you. [Take signed forms.] If you have completed the questionnaires that were mailed to you, you can give them to me now [collect Intake Questionnaire, Rothbart Infant Behavior Questionnaire, and Communication and Symbolic Behavior Scales Caregiver

Questionnaires if completed, otherwise]: If you have them with you, you may complete them now, if not, here are new copies to fill in [allow the parent to complete the questionnaires before collecting and proceeding to 4].

4. Now we will prepare your child for the motion capture session. [Put suit on infant. Be sure to record which suit you are using on the observation sheet]. We will begin by calibrating the motion capture system so that the system is most effective when collecting the data from your child's actions. You may stop us at any time if you or your child become uncomfortable or tired, and we can take a break or you may choose to leave the study [One researcher (or parent, if preferred) holds infant still to calibrate the system].

5. We will now have your child sit on the mats with the assistance of a researcher. He/She will be given three to five minutes to explore and play with any combination of the toys in any manner. I will interact normally with your child, but I will not point out any particular toy or its function. [With child seated next to or adjacent to the examiner, simultaneously present each of the three toys. After 1 minute elapses, if the infant has explored only one toy, take away that toy but leave it within reach on the table, while pushing the other unexplored toys closer to the child. Repeat step 2 if still only plays with one toy after the second minute. All toys are removed after 3 minutes.]

6. I will perform three pull-to-sit tasks. Your infant will begin in a supine position on the mats and then I will gently pull him/her to a sitting position. [This task will be completed three times. The trials do not have to be in succession. The infant is free to play between trials. Do not encourage the child or react positively or negatively during or after completion of the task]. This task will be repeated two more times throughout this session. For the second task, I will place your child in a supine position and push his/her hands to his/her sides while my assistant holds a toy directly above the child's chest a little above arm's reach. The child's hands will be freed at the same time, and the consequent movement will be recorded. This will be repeated twice throughout the motion capture session. [This task will be completed three times. The trials do not have to be in succession. The infant is free to play between trials. Do not encourage the child or react positively or negatively during or after completion of the task]. For the third task, I will place your child in a sitting position, and then I will draw his/her attention to an object of interest on the right side of his/her peripheral vision. I will then move the object in a level motion across his/her field of vision to the left periphery, where his/her head motion will be recorded. This task will be repeated twice, and then will be conducted three times with the object of interest sweeping from the left to right. [This task will be completed three times. Trials do not have to be in succession. The infant is free to play between trials.] For the final task, I will again place your infant in a sitting position, and I will provide him/her with a toy to explore and play with for one to two minutes. After your infant is accustomed to the toy, I will substitute the toy with an identical toy of a different mass, and the consequent movement will be recorded. This task will be repeated twice throughout the motion capture session. Researchers will prevent your child from leaving the mats throughout this session. Please notify us at any time if you or your infant are uncomfortable, and please feel free to ask any questions as they may arise. [Perform tasks as directed, heeding any concerns the parent raises while following the procedure closely.]

7. Please complete the Communication and Symbolic Behavioral Scales Parent Perception questionnaire. [Hand parent Appendix J.] This allows you to tell us if your child's behavior during this session is typical. [Collect questionnaire when completed.] Thank you very much for your time, if you have any further questions or wish to withdraw your participation, you may call the Principal Investigator, Dr. Yiannis Aloimonos during business hours at [REDACTED] or e-mail him anytime at yiannis@cs.umd.edu.

Observation Sheet

Participant ID: _____

Date: _____

Data Recorder: _____

Researchers: _____

Motion Capture Session

Motion Capture Suit used:	Hat:	_____	Bib:	_____
Waistband: _____	Left Elbow:	_____	Right Elbow:	_____
Left Wrist: _____	Right Wrist:	_____	Left Knee:	_____
Right Knee: _____	Left Sock:	_____	Right Sock:	_____

How does the infant react to the markers initially?

1	2	3	4	5
Indifferent		Some interest		Complete interest

Object exploration assessment:

Toy placement (from left to right, infant's perspective):

Infant's behaviors during the three minutes:

How was the infant's overall behavior during the object exploration assessment?

1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	

Comments:

How does the infant react to the markers?

1	2	3	4	5
Indifferent		Some interest		Complete interest

Pull-to-sit

Researcher: _____

Trial 1:

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

Is there a noticeable degree of head lag (circle one)? YES NO

How was the infant's behavior during the pull-to-sit?

1 2 3 4 5

Uncooperative Somewhat cooperative Fully cooperative

Comments:

Trial 2:

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

Is there a noticeable degree of head lag (circle one)? YES NO

How was the infant's behavior during the pull-to-sit?

1 2 3 4 5

Uncooperative Somewhat cooperative Fully cooperative

Comments:

Trial 3:

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

Is there a noticeable degree of head lag (circle one)? YES NO

How was the infant's behavior during the pull-to-sit?

1 2 3 4 5

Uncooperative Somewhat cooperative Fully cooperative

Comments:

Reaching task

Researcher holding toy: _____

Trial 1: What object? _____ Object orientation? _____

Hand orientation? Horizontal Vertical Otherwise, specify: _____

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

How was the infant's behavior during the reach?

1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	

Comments:

Trial 2: What object? _____ Object orientation? _____

Hand orientation? Horizontal Vertical Otherwise, specify: _____

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

How was the infant's behavior during the pull-to-sit?

1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	

Comments:

Trial 3: What object? _____ Object orientation? _____

Hand orientation (circle one)? Horizontal Vertical Otherwise, specify: _____

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

How was the infant's behavior during the pull-to-sit?

1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	

Comments:

Trial 1: What object? _____ Object orientation? _____

Hand orientation? Horizontal Vertical Otherwise, specify: _____

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

How was the infant's behavior during the reach?

1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	

Comments:

Trial 2: What object? _____ Object orientation? _____

Hand orientation? Horizontal Vertical Otherwise, specify: _____

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

How was the infant's behavior during the pull-to-sit?

1 2 3 4 5

Uncooperative Somewhat cooperative Fully cooperative

Comments:

Trial 3: What object? _____ Object orientation? _____

Hand orientation (circle one)? Horizontal Vertical Otherwise, specify: _____

Note the behavior of the legs (circle one for left and one for right):

Left: Extended Bent Kicking Right: Extended Bent Kicking

How was the infant's behavior during the pull-to-sit?

1 2 3 4 5

Uncooperative Somewhat cooperative Fully cooperative

Comments:

Visual Tracking

Researcher moving toy:

Trial 1: What object? _____

The infant's head moved:

1 2 3 4 5

Not at all Halfway All the way

How was the infant's behavior during the task?

1 2 3 4 5

Uncooperative Somewhat cooperative Fully cooperative

Comments:

Trial 2: What object? _____

The infant's head moved:

1 2 3 4 5

Not at all		Halfway		All the way
How was the infant's behavior during the task?				
1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	
Comments:				

Trial 3: What object? _____

The infant's head moved:

1	2	3	4	5
Not at all		Halfway		All the way
How was the infant's behavior during the task?				
1	2	3	4	5
Uncooperative	Somewhat cooperative		Fully cooperative	
Comments:				

Postural Control

Researcher offering toys:

Trial 1: What object was presented first? _____ Second?

How was the infant's behavior during the task?

1 2 3 4 5
Uncooperative Somewhat cooperative Fully cooperative

Comments:

Trial 2: What object was presented first? _____ Second?

How was the infant's behavior during the task?

1 2 3 4 5
Uncooperative Somewhat cooperative Fully cooperative

Comments:

Trial 3: What object was presented first? _____ Second?

How was the infant's behavior during the task?

1 2 3 4 5
Uncooperative Somewhat cooperative Fully cooperative

Comments:

Action log for motion capture session:

Video time	Behavior

Appendix A.4 – IRB Addendum 03/11/2011

- 1) State what is being proposed and where in the protocol and/or consent what was changed.
- 2) Provide the rationale/justification for the change.
- 3) State what impact the change has on risks to participants. Please state the number of currently enrolled participants and if the change in risk will require re-consent. If the changes will not require re-consent, please state why.
- 4) State whether the change has an impact on the scientific integrity of the study, (i.e. decreases, increases, no impact).
- 5) List the documents included with the application that have been modified (consent forms, flyers, data collection forms, surveys). State what has been changed in each modified document.**

Team AMIRA
Consent for Photography/Filming

Audio/visual recordings publicize the study Analyzing the Movement of Infants at Risk for Autism Spectrum Disorders (AMIRA). For the purpose of publicly promoting the study, team AMIRA requests permission for your child to be photographed or videotaped.

I give consent for _____, to have his/her photograph taken or to be filmed by team AMIRA for use in marketing and promotional materials such as flyers.

Permission for use of these images may be withdrawn by notifying team AMIRA in writing at _____.

S i g n a t u r e _____
Date _____

Relationship
to child/ward _____

Address:

Phone:

Appendix B – Matlab code

B.1 – angle3d

```
function theta = angle3d(v1, v2)
% angle3d - Computes the angle between two vectors v1 and v2
% (radians).
%
%   input args:
%           v1 - the first vector
%           v2 - the second vector
%
%   return vals:
%           theta - the angle between v1 and v2

cos_theta = dotProduct(v1, v2) / (magnitude(v1) * magnitude(v2));
theta = acos(cos_theta);
end
```

B.2 - computePullToSitValues

```
function data = computePullToSitValues(frames, subjectID, trialNum,
isHighRisk)
% computePullToSitValues - Computes the motion indicators for the
% pull-to-sit action, and saves them to a file.
%
%   input args:
%           frames - matrix containing labeled frame data
%           subjectID - ID number of the subject
%           trialNum - trial number of the action
%           isHighRisk - 0 for low-risk subject, 1 for high-risk
%
%   return vals:
%           data - struct containing all motion indicators for
the
%                   action

% Angle vs. time graph
angleVsTime = headlag(frames);
angleVsTime = angleVsTime';

angleVsTimeBeforeHolesFixed = angleVsTime;
figure;
plot(angleVsTimeBeforeHolesFixed);

% Fix holes in graph (linear interpolation)
startIndex = 1;
while angleVsTime(startIndex) == -1 || angleVsTime(startIndex) == -2
|| angleVsTime(startIndex) == -3
    startIndex = startIndex + 1;
end
angleVsTime = angleVsTime(startIndex:end);
for i = 1:size(angleVsTime)
    if angleVsTime(i) == -1 || angleVsTime(i) == -2 ||
angleVsTime(i) == -3
        lastFrame = i - 1;
        nextFrame = -1;
        for nextIndex = i+1:size(angleVsTime)
```

```

        if angleVsTime(nextIndex) > 0
            nextFrame = nextIndex;
            break;
        end
    end

    if nextFrame == -1
        angleVsTime = angleVsTime(1:lastFrame);
        break;
    else
        dif = nextFrame - lastFrame;
        for fixFrame = lastFrame+1:nextFrame-1
            nextRatio = (fixFrame - lastFrame) / dif;
            lastRatio = 1 - nextRatio;
            angleVsTime(fixFrame) = angleVsTime(lastFrame) *
lastRatio + angleVsTime(nextFrame) * nextRatio;
        end
    end
end
end

% Plot graph
figure;
plot(angleVsTime);

% Average angle
averageAngle = mean(angleVsTime);

% Max angle
maxAngle = max(angleVsTime);

% Max angle location
for i = 1:size(angleVsTime)
    if abs(angleVsTime(i) - maxAngle) < 0.1
        maxAngleLocationIndex = i;
        break;
    end
end
maxAngleLocation = maxAngleLocationIndex / size(angleVsTime,1);

% Derivative graph
angleVsTimeDerivative = diff(angleVsTime);
figure;
plot(angleVsTimeDerivative);

% Max derivative
maxDerivative = max(angleVsTimeDerivative);

% Put all of this data in a struct, and save it
data.isHighRisk = isHighRisk;
data.angleVsTimeBeforeHolesFixed = angleVsTimeBeforeHolesFixed;
data.angleVsTime = angleVsTime;
data.averageAngle = averageAngle;
data.maxAngle = maxAngle;
data.maxAngleLocation = maxAngleLocation;
data.angleVsTimeDerivative = angleVsTimeDerivative;
data.maxDerivative = maxDerivative;

```

```

savefile = strcat('subject', subjectID, '_pullToSit_trial',
trialNum, '.mat');
savedir = 'C:\Users\Jimmy\Desktop\amira_local\output\';
save(strcat(savedir, savefile), 'data');

```

```
end
```

B.3 - computeVisualTrackingZ

```

function [angles] = computeVisualTrackingZ(frames, startFrame,
endFrame, subjectID, trialNum)
% computeVisualTrackingZ - Computes the angle between the head and
toy for
% a visual tracking action.
%
% input args:
% frames - matrix of frames
% startFrame - frame number of start of action
% endFrame - frame number of end of action
% subjectID - ID number of the subject
% trialNum - trail number of the action
%
% return vals:
% angles - vector of the angles between head direction
and
% toy

global HEAD_BL
global HEAD_BR
global HEAD_F
global MARKER

angles = zeros(1, endFrame - startFrame);
framesIgnored = 0;

% Do for each frame in the action
for i = startFrame:endFrame
    % Check that all necessary points are set
    if (frames(i).isSet(HEAD_BL) && frames(i).isSet(HEAD_BR) && ...
        frames(i).isSet(HEAD_F) && frames(i).isSet(MARKER))
        % Store 3-d points in frames in shorter temp variables
        headLeft = frames(i).labelledPoints(HEAD_BL);
        headRight = frames(i).labelledPoints(HEAD_BR);
        headFront = frames(i).labelledPoints(HEAD_F);
        object = frames(i).labelledPoints(MARKER);

        % Vector from head back left to head front
        v1.xval = headFront.xval - headLeft.xval;
        v1.yval = headFront.yval - headLeft.yval;
        v1.zval = headFront.zval - headLeft.zval;
        % Vector from head back right to head front
        v2.xval = headFront.xval - headRight.xval;
        v2.yval = headFront.yval - headRight.yval;
        v2.zval = headFront.zval - headRight.zval;

        % Convert v1 and v2 to unit vectors by dividing components
by
        % the magnitude of each vector
        v1mag = magnitude(v1);

```

```

v2mag = magnitude(v2);
v1.xval = v1.xval / v1mag;
v1.yval = v1.yval / v1mag;
v1.zval = v1.zval / v1mag;
v2.xval = v2.xval / v2mag;
v2.yval = v2.yval / v2mag;
v2.zval = v2.zval / v2mag;

% a = v1 + v2
a.xval = (v1.xval + v2.xval);
a.yval = (v1.yval + v2.yval);
a.zval = (v1.zval + v2.zval);
% b is the vector from the head front to the object
b.xval = object.xval - headFront.xval;
b.yval = object.yval - headFront.yval;
b.zval = object.zval - headFront.zval;

% Calculate angle between vectors a and b
cosang = dotProduct(a, b) / (magnitude(a) * magnitude(b));
degrees = acos(cosang);

% Store angle for this frame
angles(i - startFrame + 1) = (degrees * 360) / (2 * pi);

else
    % At least one of the points we need was not labelled for
this
    % frame. Ignore frame. Count number of ignored frames to
determine
    % whether the data is usable.
framesIgnored = framesIgnored + 1;
if(i > 1)
    angles(i - startFrame + 1) = angles(i - startFrame);
else
    angles(i - startFrame + 1) = 0;
end
end
end

% Average angle
averageAngle = mean(angles);

% Max angle
maxAngle = max(angles);

%Calculate proportion of frames gone when max angle occurs
for i = 1:size(angles)
    if abs(angles(i) - maxAngle) < 0.00001
        maxAngleLocationIndex = i;
        break;
    else
        maxAngleLocationIndex = 0;
    end
end
maxAngleLocation = maxAngleLocationIndex / size(angles,1);

% Derivative graph
angleVsTimeDerivative = diff(angles);

```

```

% Max derivative
maxDerivative = max(angleVsTimeDerivative);

% Proportion of frames ignored because of missing points
percentframesIgnored = framesIgnored / (endFrame - startFrame) *
100;

% Put all of this data in a struct, and save it
data.isHighRisk = 0;
data.angleVsTime = angles;
data.averageAngle = averageAngle;
data.maxAngle = maxAngle;
data.maxAngleLocation = maxAngleLocation;
data.angleVsTimeDerivative = angleVsTimeDerivative;
data.maxDerivative = maxDerivative;
data.percentFramesIgnored = percentframesIgnored;

savefile = strcat('subject', subjectID, '_visualTrackingZ_trial',
trialNum, '.mat');
savedir = 'V:\Users\Brendan Wray\Desktop\Team AMIRA\output
\visualTracking\';
save(strcat(savedir, savefile), 'data');

end

```

B.4 – distance3d

```

function val = distance3d(p1, p2)
% distance3d - Computes the euclidean distance between two points.
%
%   input args:
%       p1 - the first point
%       p2 - the second point
%
%   return vals:
%       val - the distance between p1 and p2

val = sqrt((p1.xval - p2.xval)^2 + (p1.yval - p2.yval)^2 + (p1.zval
- p2.zval)^2);
end

```

B.5 - dotProduct

```

function val = dotProduct(v1, v2)
% dotProduct - Computes the dot product of two vectors.
%
%   input args:
%       v1 - the first vector
%       v2 - the second vector
%
%   return vals:
%       val - the dot product of v1 and v2

val = v1.xval * v2.xval + v1.yval * v2.yval + v1.zval * v2.zval;
end

```

B.6 – drawline

```

function drawline(p1, p2)
% drawline - Draws a line on a 3D plot between two points.
%
%   input args:
%           p1 - the first point
%           p2 - the second point
%
%   return vals:
%           None

plot3([p1.xval p2.xval], [p1.yval p2.yval], [p1.zval p2.zval]);
end

```

B.7 - equalPoints

```

function b = equalPoints(p1, p2)
% equalPoints - Returns 1 if two points are equal (same location),
and
% 0 otherwise.
%
%   input args:
%           p1 - the first point
%           p2 - the second point
%
%   return vals:
%           b - boolean equivalence value

b = (p1.xval == p2.xval) && (p1.yval == p2.yval) && (p1.zval ==
p2.zval);
end

```

B.8 - generatePermutations

```

function M = generatePermutations(n, range)
% generatePermutations - Generates and returns a matrix containing
all
% possible ways of picking n numbers between 1 and range (no
duplicates).
%
%   input args:
%           n - size of each permutation
%           range - maximum value allowed in each permutation
%
%   return vals:
%           M - matrix of permutations

M = [];
if(n <= 0)
    return;
elseif(n == 1)
    M = linspace(1, range, range)';
    return;
end

temp = generatePermutations(n-1, range);
for i=1:range
    for j=1:size(temp,1)
        if(~contains(i, temp(j,:)))
            M = [M; i temp(j,:)];
        end
    end
end

```

```

        end
    end
end

function b = contains(val, list)
% contains - Helper function for generatePermutations. Returns 1 if
val
% is an element of list, or 0 otherwise.
%
% input args:
%     val - value to search for
%     list - set of values through which to search
%
% return vals:
%     b - 1 if val is in list, 0 otherwise

    b = 0;
    for i=1:size(list,2)
        if(list(i) == val)
            b = 1;
            return;
        end
    end
end
end

```

B.9 - headlag

```

function angles = headlag(frames)
% headlag - Calculates the angle between the head and chest (in
degrees)
% for all frames, and returns a vector of the values. Where errors
occur,
% the angle value will be replaced by an error code. Error codes:
% -1: Required labels not set for this frame
% -2: None of the expected cases matched the cosine angle formula
output.
% This probably means that labels are incorrect in this frame.
% -3: Calculated angle value outside expected range. Again,
indicates
% incorrect labels.
%
% input args:
%     frames - labeled frame data of marker coordinates
%
% return vals:
%     angles - vector of angle values for each frame

global HEAD_BL
global HEAD_BR
global HEAD_F
global SHOULDER_L
global SHOULDER_R
global CHEST

angles = zeros(1, size(frames, 2));
epsilon = 1; % degrees

for i = 1:size(frames, 2)

```

```

    % Check that all necessary points are set
    if (frames(i).isSet(HEAD_BL) && frames(i).isSet(HEAD_BR) && ...
        frames(i).isSet(HEAD_F) && frames(i).isSet(SHOULDER_L)
&& ...
        frames(i).isSet(SHOULDER_R) && frames(i).isSet(CHEST))
    % Get the points we will need, and store them as column
vectors
    mxh = (frames(i).labelledPoints(HEAD_BL).xval +
frames(i).labelledPoints(HEAD_BR).xval) / 2;
    myh = (frames(i).labelledPoints(HEAD_BL).yval +
frames(i).labelledPoints(HEAD_BR).yval) / 2;
    mzh = (frames(i).labelledPoints(HEAD_BL).zval +
frames(i).labelledPoints(HEAD_BR).zval) / 2;
    headBack = [mxh; myh; mzh];

    fhx = frames(i).labelledPoints(HEAD_F).xval;
    fhy = frames(i).labelledPoints(HEAD_F).yval;
    fhz = frames(i).labelledPoints(HEAD_F).zval;
    headFront = [fhx; fhy; fhz];

    slx = frames(i).labelledPoints(SHOULDER_L).xval;
    sly = frames(i).labelledPoints(SHOULDER_L).yval;
    slz = frames(i).labelledPoints(SHOULDER_L).zval;
    leftShoulder = [slx; sly; slz];

    srx = frames(i).labelledPoints(SHOULDER_R).xval;
    sry = frames(i).labelledPoints(SHOULDER_R).yval;
    srz = frames(i).labelledPoints(SHOULDER_R).zval;
    rightShoulder = [srx; sry; srz];

    midShoulders = (leftShoulder + rightShoulder) / 2;

    chestX = frames(i).labelledPoints(CHEST).xval;
    chestY = frames(i).labelledPoints(CHEST).yval;
    chestZ = frames(i).labelledPoints(CHEST).zval;
    chest = [chestX; chestY; chestZ];

    % Get vectors
    StoHB = headBack - midShoulders;
    StoHF = headFront - midShoulders;
    StoC = chest - midShoulders;

    % Project onto plane (defined by normal vector connecting
    % shoulders). Note that since we have used column vectors,
dot
    % product is a' * b.
    planeNormal = leftShoulder - rightShoulder;
    unitNormal = planeNormal / norm(planeNormal);
    pStoHB = StoHB - (StoHB' * unitNormal) * unitNormal;
    pStoHF = StoHF - (StoHF' * unitNormal) * unitNormal;
    pStoC = StoC - (StoC' * unitNormal) * unitNormal;

    % Now we can finally get angles
    % Use cosine angle formula
    % theta(in degrees) = acos((u dot v) / (norm(u) * norm(v)))
* 180/pi;
    aCtoHF = acos((pStoC' * pStoHF) / (norm(pStoC) *
norm(pStoHF))) * 180/pi;

```



```

        aCtoHB = acos((pStoC' * pStoHB) / (norm(pStoC) *
norm(pStoHB))) * 180/pi;
        aHFtoHB = acos((pStoHF' * pStoHB) / (norm(pStoHF) *
norm(pStoHB))) * 180/pi;

        % Cosine angle formula always gives the interior angle.
Depending on
        % the head position we sometimes need the exterior angle.
a = aCtoHF;
b = aHFtoHB;
c = aCtoHB;
% If normal case, a + b = c
% If straddling, a + b = 360 - c
% If behind, b + c = a
if abs(a + b - c) < epsilon
    angles(i) = c;
elseif abs(a + b - (360 - c)) < epsilon
    angles(i) = 360 - c;
elseif abs(b + c - a) < epsilon
    angles(i) = 360 - c;
else
    % Something went wrong, return error code.
    angles(i) = -2;
end

if angles(i) > 270 || angles(i) < 90
    % None of our head angles should be outside this range,
so
    % return error code.
    angles(i) = -3;
end
else
    % At least one of the points we need was not labelled for
this
    % frame. Return error code.
    angles(i) = -1;
end
end
end

```

B.10 - identifyBodyPoints

```

function frames = identifyBodyPoints(frames, init,
useVisualTrackingMarker)
% identifyBodyPoint - Main function for labeling data.
%
% input args:
%     frames - unlabeled frame data of marker coordinates
%     init - the frame number for a single pre-labeled
frame
%     useVisualTrackingMarker - 1 if an 11th point on a
toy will
%     be labeled, or 0 otherwise
%
% return vals:
%     frames - labeled frame data of marker coordinates

% Label forwards, from the init frame to the end of the video.
frames = identifyBodyPointsHelper(frames, init, init+1, size(frames,
2), useVisualTrackingMarker);

```

```

% Label backwards, from the end of the video to the beginning.
frames = identifyBodyPointsHelper(frames, init, size(frames, 2)-1,
1, useVisualTrackingMarker);
% Label forwards, from the beginning of the video to the init frame.
frames = identifyBodyPointsHelper(frames, init, 2, init,
useVisualTrackingMarker);
end

```

B.11 - identifyBodyPointsHelper

Contents

[Initialization](#)

[Label data](#)

[Recover General](#)

[Simultaneous Recovery](#)

```

function frames = identifyBodyPointsHelper(frames, init, startFrame,
endFrame, useVisualTrackingMarker)
% identifyBodyPointsHelper - This function contains all of the heavy
work
% for labeling points. Labels all frames between startFrame and
endFrame,
% using the labels set in the init frame.
%
%   input args:
%       frames - unlabeled frame data of marker coordinates
%       init   - the frame number for a single pre-labeled
frame
%       startFrame - frame at which to start labeling
%       endFrame   - frame at which to stop labeling
%       useVisualTrackingMarker - 1 if an 11th point on a
toy will
%                               be labeled, or 0 otherwise
%
%   return vals:
%       frames - labeled frame data of marker coordinates

global HEAD_BL
global HEAD_BR
global HEAD_F
global SHOULDER_L
global SHOULDER_R
global CHEST
global HAND_L_IN
global HAND_L_OUT
global HAND_R_IN
global HAND_R_OUT
global MARKER

```

Initialization

```

% Thresholds for when to accept/deny labels
DISTANCE_THRESHOLD = 0.020;
ANGLE_THRESHOLD = pi / 20;

```

```

% Set group and point numbers
if useVisualTrackingMarker
    numPoints = 11;
    numGroups = 5;
else
    numPoints = 10;
    numGroups = 4;
end

% Initialize group numbers. Groups represent rigid bodies (points
that do not
% move relative to each other).
groupNum(HEAD_BL) = 1;
groupNum(HEAD_BR) = 1;
groupNum(HEAD_F) = 1;
groupNum(SHOULDER_L) = 2;
groupNum(SHOULDER_R) = 2;
groupNum(CHEST) = 2;
groupNum(HAND_L_IN) = 3;
groupNum(HAND_L_OUT) = 3;
groupNum(HAND_R_IN) = 4;
groupNum(HAND_R_OUT) = 4;

groupThreshhold(1) = 0.2; % head
groupThreshhold(2) = 0.2; % body
groupThreshhold(3) = 0.1; % left hand
groupThreshhold(4) = 0.1; % right hand
if useVisualTrackingMarker
    groupNum(MARKER) = 5;
    groupThreshhold(5) = 0.1;
end

% Inner function for getting each of the body markers in a group
function A = groupIndexes(group)
    A = [];
    for index=1:numPoints
        if(groupNum(index) == group)
            A = [A index];
        end
    end
end

% Inner function for checking if two body markers are in the same
group
function n = sameGroup(i, j)
    n = (groupNum(i) == groupNum(j));
end

% Initialize initDist, a matrix containing the starting distances
between
% all pairs of points in the same group.
initDist = zeros(numPoints, numPoints);
for i = 1:numPoints
    for j = i:numPoints
        if(sameGroup(i,j))
            if frames(init).isSet(i) && frames(init).isSet(j)

```

```

        initDist(i, j) =
distance3d(frames(init).labelledPoints(i),
frames(init).labelledPoints(j));
    else
        initDist(i, j) = 9999; % Fake value, two points will
never have this much distance
    end
    initDist(j, i) = initDist(i, j);
end
end
end

% Initialize counters for algorithm debugging
unlabeled = 0;
over10 = 0;
labels = 0;
recoveredByProximity = 0;
recovered = zeros(1, numPoints);
for i=1:numPoints
    recovered(i) = 0;
end
recoveredGroup = zeros(1, numGroups);
for i=1:numGroups
    recoveredGroup(i) = 0;
end

% Set direction and oppDirection (1 for forwards, -1 for backwards)
if startFrame > endFrame
    direction = -1;
else
    direction = 1;
end
oppDirection = direction * -1;

```

Label data

```

for f = startFrame:direction:endFrame
    % Use temporal coherence and labels in previous frame, assign
labels to
    % all obvious points.
    tempPoints = frames(f).rawPoints;
    i = 1;
    while i < size(tempPoints,2)
        min_d = DISTANCE_THRESHOLD;
        min_index = -1;
        matches = 0;
        % Find best match for this point
        for j=1:numPoints
            if(frames(f+oppDirection).isSet(j) &&
~frames(f).isSet(j))
                d = distance3d(frames(f
+oppDirection).labelledPoints(j), tempPoints(i));
                if (d < DISTANCE_THRESHOLD)
                    matches = matches + 1;
                end
                if(d < min_d)
                    min_d = d;
                    min_index = j;
                end
            end
        end
        i = i + 1;
    end
end

```

```

        end
    end
    if(min_index ~= -1)
        % Only keep match if there were no other matches
        if(matches > 1)
            i = i + 1;
            continue;
        end
        % Test best match against points in the previous frame
in the
        % same group
        valid = 1;
        for testP=1:numPoints
            if(sameGroup(min_index, testP) && frames(f
+oppDirection).isSet(testP) && testP ~= min_index)
                dist = distance3d(frames(f
+oppDirection).labelledPoints(testP), tempPoints(i));
                if(dist < initDist(min_index, testP) * (1-
groupThreshold(groupNum(testP))) || dist > initDist(min_index,
testP) * (1+groupThreshold(groupNum(testP))))
                    valid = 0;
                end
            end
        end
        end
        if(valid)
            % Assign label
            recoveredByProximity = recoveredByProximity + 1;
            frames(f).isSet(min_index) = 1;
            frames(f).labelledPoints(min_index) = tempPoints(i);
            tempPoints(i) = [];
            i = i - 1;
        end
    end
    i = i + 1;
end

```

Recover General

```

% From this line on, points are assumed to be 'lost' and must be
% recovered.
for thisP=1:numPoints
    if(~frames(f).isSet(thisP))
        % Start with set of candidates as all remaining points
        candidates = tempPoints;
        for thatP=1:numPoints
            if(frames(f).isSet(thatP) && thisP ~= thatP)
                % Remove candidates based on distance from
labeled
                % points in previous frames
                if(size(candidates,2) >= 1)
                    fdiff = 5;
                    % Fix value of fdiff when close to boundary
of
                    % frames array
                    if direction == 1
                        if(f <= fdiff), fdiff = f-1; end
                    else

```

```

        if(f >= size(frames,2)-fdiff), fdiff =
size(frames,2) - f; end
    end
    for i=1:fdiff
        if(frames(f+i*oppDirection).isSet(thisP)
&& frames(f+i*oppDirection).isSet(thatP))
            dist1 = distance3d(frames(f
+i*oppDirection).labelledPoints(thisP), frames(f
+i*oppDirection).labelledPoints(thatP));
            j = 1;
            while j <= size(candidates, 2)
                dist2 =
distance3d(candidates(j), frames(f
+i*oppDirection).labelledPoints(thatP));
                dif = abs(dist1 - dist2);
                if(dif > DISTANCE_THRESHOLD *
i)
                    candidates(j) = [];
                    j = j - 1;
                end
                j = j + 1;
            end
            break;
        end
    end
    end
    % Removed labeled points based on direction from
points
    % in previous frames in the same group
    if(sameGroup(thisP, thatP))
        candidates =
pointsWithinThreshold(frames(f).labelledPoints(thatP), candidates,
initDist(thisP, thatP), groupThreshold(groupNum(thisP)));
        if(size(candidates,2) >= 1)
            fdiff = 5;
            % Fix value of fdiff when close to
boundary of
            % frames array
            if direction == 1
                if(f <= fdiff), fdiff = f-1; end
            else
                if(f >= size(frames,2)-fdiff), fdiff
= size(frames,2) - f; end
            end
        end
    end
    for i=1:fdiff
        if(frames(f
+i*oppDirection).isSet(thisP) && frames(f
+i*oppDirection).isSet(thatP))
            v1.xval = frames(f
+i*oppDirection).labelledPoints(thisP).xval - frames(f
+i*oppDirection).labelledPoints(thatP).xval;
            v1.yval = frames(f
+i*oppDirection).labelledPoints(thisP).yval - frames(f
+i*oppDirection).labelledPoints(thatP).yval;

```



```

        for recoverSize=size(missingPoints,2):-1:2
            if(size(candidates,2) >= recoverSize)
                % Get all possible combinations of points as
candidates
                % for satisfying the missing group
                candidateIndexes =
generatePermutations(recoverSize, size(candidates,2));
                minSum = 999;
                minIndex = -1;
                c = 1;
                while c <= size(candidateIndexes,1)
                    stillValid = 1;
                    sum = 0;

                    for candidatePointIndex1=1:recoverSize
                        p1 =
candidates(candidateIndexes(c,candidatePointIndex1));

                        % Check against set points
                        for setPointIndex = 1:size(setPoints,2)
                            % If not valid distance remove this
                            % candidate combination
                            p2 =
frames(f).labelledPoints(setPoints(setPointIndex));
                            d = distance3d(p1, p2);
                            iDist =
initDist(missingPoints(candidatePointIndex1),setPoints(setPointIndex
));
                            sum = sum + abs(d - iDist);
                            if(d > (iDist * (1 +
groupThreshold(i))) || d < (iDist * (1 - groupThreshold(i))))
                                % Remove candidate combination
                                candidateIndexes(c,:) = [];
                                c = c - 1;
                                stillValid = 0;
                                break;
                            end
                        end
                    end

                    if(~stillValid), break; end

                    % Check against other missing points
                    for candidatePointIndex2 =
candidatePointIndex1+1:recoverSize
                        % If not valid distance remove this
                        % candidate combination
                        p2 =
candidates(candidateIndexes(c,candidatePointIndex2));
                        d = distance3d(p1, p2);
                        iDist =
initDist(missingPoints(candidatePointIndex1),missingPoints(candidate
PointIndex2));
                        sum = sum + abs(d - iDist);
                        if(d > (iDist * (1 +
groupThreshold(i))) || d < (iDist * (1 - groupThreshold(i))))
                            % Remove candidate combination
                            candidateIndexes(c,:) = [];
                            c = c - 1;
                        end
                    end
                end
            end
        end
    end
end

```



```

                                stillValid = 0;
                                break;
                            end
                        end
                    if(~stillValid), break; end

                end
                if(stillValid && sum < minSum)
                    minSum = sum;
                    minIndex = c;
                end
                c = c + 1;
            end
            % Now we should have eliminated most of the
candidate
            % possibilities

            % Use previous frames to eliminate more
possibilities
            c = 1;
            removedAnyPossibilities = 0;
            while(c <= size(candidateIndexes,1))
                stillValid = 1;
                for candidatePointIndex1=1:recoverSize
candidatePointIndex1+1:recoverSize
                    fdiff = 20;
                    % Fix value of fdiff when close to
boundary of
                    % frames array
                    if direction == 1
                        if(f <= fdiff), fdiff = f-1; end
                    else
                        if(f >= size(frames,2)-fdiff),
fdiff = size(frames,2) - f; end
                    end

                    % Try to remove possibilities using
the
                    % direction of the vector between
the
                    % candidate points
                    for fshift=1:fdiff
                        bpIndex1 =
missingPoints(candidatePointIndex1);
                        bpIndex2 =
missingPoints(candidatePointIndex2);
                        if(frames(f
+fshift*oppDirection).isSet(bpIndex1) && frames(f
+fshift*oppDirection).isSet(bpIndex2))
                            v1.xval = frames(f
+fshift*oppDirection).labelledPoints(bpIndex1).xval - frames(f
+fshift*oppDirection).labelledPoints(bpIndex2).xval;
                            v1.yval = frames(f
+fshift*oppDirection).labelledPoints(bpIndex1).yval - frames(f
+fshift*oppDirection).labelledPoints(bpIndex2).yval;

```

```

v1.zval = frames(f
+ fshift*oppDirection).labelledPoints(bpIndex1).zval - frames(f
+ fshift*oppDirection).labelledPoints(bpIndex2).zval;

p1 =
candidates(candidateIndexes(c,candidatePointIndex1));
p2 =
candidates(candidateIndexes(c,candidatePointIndex2));
v2.xval = p1.xval - p2.xval;
v2.yval = p1.yval - p2.yval;
v2.zval = p1.zval - p2.zval;
temp_angle = angle3d(v1,
v2);
if(temp_angle >
ANGLE_THRESHOLD * fshift)
candidateIndexes(c,:) =
[];
c = c - 1;
stillValid = 0;
removedAnyPossibilities
= 1;
break;
end
end
end
if(~stillValid),break;end
end
if(~stillValid),break;end
end
c = c + 1;
end

if(size(candidateIndexes, 1) >= 1)
% Assign labels
recoveredGroup(i) = recoveredGroup(i) + 1;
if(removedAnyPossibilities)
minIndex = 1;
end
for ind=1:recoverSize
frames(f).isSet(missingPoints(ind)) = 1;

frames(f).labelledPoints(missingPoints(ind)) =
candidates(candidateIndexes(minIndex,ind));
tempPoints =
remove(candidates(candidateIndexes(minIndex,ind)), tempPoints);
end
break;
end
end
end

% Done labeling this frame. Record statistics for output.
for i = 1:numPoints
if(frames(f).isSet(i))
labels = labels + 1;
end
end

```

```

end
if(size(tempPoints,2) > 0)
    if(frames(f).numPoints > numPoints)
        overl0 = overl0 + frames(f).numPoints - numPoints;
    end
    unlabeled = unlabeled + size(tempPoints, 2);
end
end
end
end

```

B.12 – loadDataPullToSit

```

function mat = loadDataPullToSit()
% loadDataPullToSit - Computes PCA scores and latent values for pull
to sit
% actions.
%
%   input args:
%           None
%
%   return vals:
%           None

%%%%%%%%% THESE ARE THE HIGH RISK GUYS
data(1) = load('output\pulltosit
\subject991241_pullToSit_trial2.mat');
data(2) = load('output\pulltosit
\subject366183_pullToSit_trial3.mat');
%%%%%%%%% END HIGH RISK GUYS
data(3) = load('output\pulltosit
\subject85337_pullToSit_trial3.mat');
data(4) = load('output\pulltosit
\subject85337_pullToSit_trial2.mat');
data(5) = load('output\pulltosit
\subject764624_pullToSit_trial3.mat');
data(6) = load('output\pulltosit
\subject764624_pullToSit_trial2.mat');
data(7) = load('output\pulltosit
\subject764624_pullToSit_trial1.mat');
data(8) = load('output\pulltosit
\subject548327_pullToSit_trial4.mat');
data(9) = load('output\pulltosit
\subject253790_pullToSit_trial4.mat');
data(10) = load('output\pulltosit
\subject20543_pullToSit_trial1.mat');
data(11) = load('output\pulltosit
\subject193018_pullToSit_trial3.mat');

[a data_len] = size(data);
mat = zeros(data_len, 270);
mat2 = zeros(data_len, 4);
for i = 1:data_len
    [len a] = size(data(i).data.angleVsTimeDerivative);
    for j = 1:len
        mat(i, j) = data(i).data.angleVsTimeDerivative(j);
    end

    %mat2(i, 1) = data(i).data.isHighRisk * 100;
    mat2(i, 1) = data(i).data.averageAngle;

```

```

    mat2(i, 2) = data(i).data.maxAngle;
    mat2(i, 3) = data(i).data.maxAngleLocation;
    mat2(i, 4) = data(i).data.maxDerivative;
end

```

```

obs1 = {'subject991241_pullToSit_trial2'
'subject366183_pullToSit_trial3' 'subject85337_pullToSit_trial3'
'subject85337_pullToSit_trial2' 'subject764624_pullToSit_trial3'
'subject764624_pullToSit_trial2' 'subject764624_pullToSit_trial1'
'subject548327_pullToSit_trial4' 'subject253790_pullToSit_trial4'
'subject20543_pullToSit_trial1' 'subject193018_pullToSit_trial3'};
biplot(pc(:,1:3), 'scores',score(:,1:3), 'ObsLabel', obs1);
view([30 40]);

mapcaplot(score, obs1)

```

B.13 - loadDataReach

```

function mat = loadDataReach()
% loadDataReach - Computes PCA scores and latent values for all
reach
% actions.
%
%   input args:
%               None
%
%   return vals:
%               None

%%%%%%%%% THESE ARE THE HIGH RISK GUYS
data(1) = load('output\reach
\subject991241_reach_trial1horizontal.mat');
data(2) = load('output\reach
\subject991241_reach_trial1vertical.mat');
data(3) = load('output\reach
\subject991241_reach_trial2vertical.mat');
data(4) = load('output\reach
\subject991241_reach_trial3horizontal.mat');
data(5) = load('output\reach
\subject991241_reach_trial3vertical.mat');
data(6) = load('output\reach
\subject991241_reach_trial4vertical.mat');
data(7) = load('output\reach
\subject057164_reach_trial1horizontal.mat');
data(8) = load('output\reach
\subject057164_reach_trial1vertical.mat');
data(9) = load('output\reach
\subject057164_reach_trial2vertical.mat');
%%%%%%%%% END HIGH RISK GUYS
data(10) = load('output\reach\subject20543_reach_trial2.mat');
data(11) = load('output\reach\subject20543_reach_trial3.mat');
data(12) = load('output\reach
\subject85337_reach_trial1horizontal.mat');
data(13) = load('output\reach
\subject193018_reach_trial1vertical.mat');
data(14) = load('output\reach
\subject193018_reach_trial2vertical.mat');

```

```

data(15) = load('output\reach
\subject193018_reach_trial3vertical.mat');
data(16) = load('output\reach
\subject193018_reach_trial4vertical.mat');
data(17) = load('output\reach
\subject253790_reach_trial4horizontal.mat');
data(18) = load('output\reach
\subject253790_reach_trial4vertical.mat');
data(19) = load('output\reach
\subject253790_reach_trial5horizontal.mat');
data(20) = load('output\reach
\subject253790_reach_trial5vertical.mat');
data(21) = load('output\reach
\subject253790_reach_trial6horizontal.mat');
data(22) = load('output\reach
\subject253790_reach_trial6vertical.mat');
data(23) = load('output\reach
\subject253790_reach_trial7horizontal.mat');
data(24) = load('output\reach
\subject279227_reach_trial2horizontal.mat');
data(25) = load('output\reach
\subject279227_reach_trial3horizontal.mat');
data(26) = load('output\reach\subject548327_reach_trial2.mat');

[a data_len] = size(data);
mat2 = zeros(data_len, 6);
mat3 = zeros(data_len, 3);
mat4 = zeros(data_len, 130);
for i = 1:data_len
    % The following builds the matrix of Data for the PCA
    if(isfield(data(i).data, 'avgVelLeft'))
        mat2(i, 1) = data(i).data.avgVelLeft;
    end
    if(isfield(data(i).data, 'avgAccLeft'))
        mat2(i, 2) = data(i).data.avgAccLeft;
    end
    if(isfield(data(i).data, 'progUnitsLeft'))
        mat2(i, 3) = data(i).data.progUnitsLeft;
    end
    if(isfield(data(i).data, 'avgVelRight'))
        mat2(i, 4) = data(i).data.avgVelRight;
    end
    if(isfield(data(i).data, 'avgAccRight'))
        mat2(i, 5) = data(i).data.avgAccRight;
    end
    if(isfield(data(i).data, 'progUnitsRight'))
        mat2(i, 6) = data(i).data.progUnitsRight;
    end

    if(abs(mat2(i, 1)) > abs(mat2(i, 4)))
        mat3(i, 1) = mat2(i, 1);
        mat3(i, 2) = mat2(i, 2);
        mat3(i, 3) = mat2(i, 3) + 1;
        [a len] = size(data(i).data.velLeft);
        for j = 1:130
            if(j < len);
                mat4(i, j) = data(i).data.velLeft(j);
            end
        end
    end
end

```

```

        end
    else
        mat3(i, 1) = mat2(i, 4);
        mat3(i, 2) = mat2(i, 5);
        mat3(i, 3) = mat2(i, 6) + 1;
        [a len] = size(data(i).data.velRight);
        for j = 1:130
            if j < len;
                mat4(i, j) = data(i).data.velRight(j);
            end
        end
    end
end
end

% Begin PCA
[pc,score,latent,tsquare] = princomp(mat4);

%obs12 = {'991241_1hz' '991241_1vt' '991241_2vt' '991241_3hz'
'991241_3vt' '991241_3vt' '057164_1hz' '057164_1vt' '057164_2vt'};
obs1 = {'991241_1hz' '991241_1vt' '991241_2vt' '991241_3hz'
'991241_3vt' '991241_3vt' '057164_1hz' '057164_1vt' '057164_2vt'
'subject20543_reach_trial2' 'subject20543_reach_trial3'
'subject85337_reach_trial1horizontal'
'subject193018_reach_trial1vertical'
'subject193018_reach_trial2vertical'
'subject193018_reach_trial3vertical'
'subject193018_reach_trial4vertical'
'subject253790_reach_trial4horizontal'
'subject253790_reach_trial4vertical'
'subject253790_reach_trial5horizontal'
'subject253790_reach_trial5vertical'
'subject253790_reach_trial6horizontal'
'subject253790_reach_trial6vertical'
'subject253790_reach_trial7horizontal'
'subject279227_reach_trial2horizontal'
'subject279227_reach_trial3horizontal'
'subject548327_reach_trial2'};
biplot(pc(:,1:3), 'scores',score(:,1:3), 'ObsLabel', obs1);
view([30 40]);

mapcaplot(score, obs1)
%scatter3(mat4(:, 1), mat4(:, 2), mat4(:, 3));
mat = mat4;
end

```

B.14 - loadDataVisualTracking

```

function mat = loadDataVisualTracking()
% loadDataVisualTracking - Computes PCA scores and latent values for
visual
% tracking actions.
%
% input args:
%             None
%
% return vals:
%             None

```

```

data(1) = load('output\Visual Tracking
\subject193018_visualTracking_trial1.mat');
data(2) = load('output\Visual Tracking
\subject193018_visualTracking_trial2.mat');
data(3) = load('output\Visual Tracking
\subject193018_visualTracking_trial3.mat');
data(4) = load('output\Visual Tracking
\subject20543_visualTracking_trial1.mat');
data(5) = load('output\Visual Tracking
\subject253790_visualTracking_trial1.mat');
data(6) = load('output\Visual Tracking
\subject253790_visualTracking_trial2.mat');
data(7) = load('output\Visual Tracking
\subject548327_visualTracking_trial3.mat');
data(8) = load('output\Visual Tracking
\subject548327_visualTracking_trial4.mat');
data(9) = load('output\Visual Tracking
\subject548327_visualTracking_trial5.mat');
data(10) = load('output\Visual Tracking
\subject85337_visualTracking_trial1.mat');
data(11) = load('output\Visual Tracking
\subject85337_visualTracking_trial3.mat');

[a data_len] = size(data);
mat = zeros(data_len, 659);
mat2 = zeros(data_len, 4);
for i = 1:data_len
    [len a] = size(data(i).data.angleVsTimeDerivative);
    for j = 1:len
        mat(i, j) = data(i).data.angleVsTimeDerivative(j);
    end

    % mat2(i, 1) = data(i).data.isHighRisk * 100;
    mat2(i, 1) = data(i).data.averageAngle;
    mat2(i, 2) = data(i).data.maxAngle;
    mat2(i, 3) = data(i).data.maxAngleLocation;
    mat2(i, 4) = data(i).data.maxDerivative;
end

[pc,score,latent,tsquare] = princomp(mat2);
% cumsum(latent)./sum(latent)

obs1 = {'subject193018_visualTracking_trial1'
'subject193018_visualTracking_trial2'
'subject193018_visualTracking_trial3'
'subject20543_visualTracking_trial1'
'subject253790_visualTracking_trial1'
'subject253790_visualTracking_trial2'
'subject548327_visualTracking_trial3'
'subject548327_visualTracking_trial4'
'subject548327_visualTracking_trial5'
'subject85337_visualTracking_trial1'
'subject85337_visualTracking_trial3'};

```

```
biplot(pc(:,1:3), 'scores', score(:,1:3), 'ObsLabel', obs1);
view([30 40]);
```

```
mapcaplot(score, obs1)
end
```

B.15 - magnitude

```
function val = magnitude(v1)
% magnitude - Computes the magnitude of a vector.
%
%   input args:
%       v1 - the vector
%
%   return vals:
%       val: the magnitude of v1
```

```
val = sqrt((v1.xval)^2 + (v1.yval)^2 + (v1.zval)^2);
end
```

B.16 - makeVideo

```
function makeVideo(frames, startFrame, displayLines, displayLabels,
labelsAreNumbers, movieName, numPts)
% makeVideo - This function plays a video of data, and then saves
the video
% to a file.
%
%   input args:
%       frames - frame data of marker coordinates
%       startFrame - the frame at which to start playing
%       displayLines - 1 to display lines on the skeleton, 0
%                   otherwise
%       displayLabels - 1 to display point labels, 0
%                   otherwise
%       labelsAreNumbers - 1 to label points by number
%                   instead of
%                       letter
%       numPts - number of labeled points to display
%
%   return vals:
%       None
```

```
format long g
global HEAD_BL
global HEAD_BR
global HEAD_F
global SHOULDER_L
global SHOULDER_R
global CHEST
global HAND_L_IN
global HAND_L_OUT
global HAND_R_IN
global HAND_R_OUT
global MARKER
```

```
% Initialize variables for plotting
xmax=0.1;
xmin=0;
```



```

ymax=0.1;
ymin=0;
zmax=0.1;
zmin=0;
labels = ['H' 'B' 'F' 'S' '2' 'C' 'L' 'O' 'I' 'R', 'M'];
maxMovieFrames = 3000;
Ashift = startFrame;

for c1=1:(size(frames,2))
    clf
    for c2=1:frames(c1).numPoints
        % Plot all points for this frame (labeled or unlabeled) and
set the
        % plot title.
        axis([xmin, xmax, ymin, ymax, zmin, zmax])
        hold on
        plot3(frames(c1).rawPoints(c2).xval,
frames(c1).rawPoints(c2).yval, frames(c1).rawPoints(c2).zval, 'ro');
        title(strcat('Frame: ', int2str(startFrame + c1), '---
Points: ', int2str(frames(c1).numPoints)),
'HorizontalAlignment','left')

        % Adjust plotting range if necessary
        if (frames(c1).rawPoints(c2).xval > xmax)
            xmax = frames(c1).rawPoints(c2).xval;
        end
        if (frames(c1).rawPoints(c2).xval < xmin)
            xmin = frames(c1).rawPoints(c2).xval;
        end
        if (frames(c1).rawPoints(c2).yval > ymax)
            ymax = frames(c1).rawPoints(c2).yval;
        end
        if (frames(c1).rawPoints(c2).yval < ymin)
            ymin = frames(c1).rawPoints(c2).yval;
        end
        if (frames(c1).rawPoints(c2).zval > zmax)
            zmax = frames(c1).rawPoints(c2).zval;
        end
        if (frames(c1).rawPoints(c2).zval < zmin)
            zmin = frames(c1).rawPoints(c2).zval;
        end

        % Display letter labels for labeled points (or numbers on
all
        % points)
        if displayLabels
            if labelsAreNumbers
                for i = 1:size(frames(c1).rawPoints, 2)
                    label = int2str(i);
                    text(frames(c1).rawPoints(i).xval,
frames(c1).rawPoints(i).yval, frames(c1).rawPoints(i).zval,label,
'HorizontalAlignment','left')
                end
            else
                for i = 1:numPts
                    if frames(c1).isSet(i)
                        label = labels(i);

```

```

                                text(frames(c1).labelledPoints(i).xval,
frames(c1).labelledPoints(i).yval,
frames(c1).labelledPoints(i).zval,label,
'HorizontalAlignment','left')
                                end
                                end
                                end
                                end
                                end

                                % Draw line segments if points are labeled
                                if(displayLines && frames(c1).isSet(HAND_L_IN) &&
frames(c1).isSet(HAND_L_OUT))
                                    drawline(frames(c1).labelledPoints(HAND_L_IN),
frames(c1).labelledPoints(HAND_L_OUT));
                                end
                                if(displayLines && frames(c1).isSet(HAND_R_IN) &&
frames(c1).isSet(HAND_R_OUT))
                                    drawline(frames(c1).labelledPoints(HAND_R_IN),
frames(c1).labelledPoints(HAND_R_OUT));
                                end
                                if(displayLines && frames(c1).isSet(HAND_L_IN) &&
frames(c1).isSet(HAND_L_OUT) && frames(c1).isSet(SHOULDER_L))

drawline(midpoint3d(frames(c1).labelledPoints(HAND_L_IN),
frames(c1).labelledPoints(HAND_L_OUT)),
frames(c1).labelledPoints(SHOULDER_L));
                                end
                                if(displayLines && frames(c1).isSet(HAND_R_IN) &&
frames(c1).isSet(HAND_R_OUT) && frames(c1).isSet(SHOULDER_R))

drawline(midpoint3d(frames(c1).labelledPoints(HAND_R_IN),
frames(c1).labelledPoints(HAND_R_OUT)),
frames(c1).labelledPoints(SHOULDER_R));
                                end
                                if(displayLines && frames(c1).isSet(SHOULDER_L) &&
frames(c1).isSet(SHOULDER_R))
                                    drawline(frames(c1).labelledPoints(SHOULDER_L),
frames(c1).labelledPoints(SHOULDER_R));
                                end
                                if(displayLines && frames(c1).isSet(SHOULDER_L) &&
frames(c1).isSet(CHEST))
                                    drawline(frames(c1).labelledPoints(SHOULDER_L),
frames(c1).labelledPoints(CHEST));
                                end
                                if(displayLines && frames(c1).isSet(SHOULDER_R) &&
frames(c1).isSet(CHEST))
                                    drawline(frames(c1).labelledPoints(SHOULDER_R),
frames(c1).labelledPoints(CHEST));
                                end
                                if(displayLines && frames(c1).isSet(HEAD_BL) &&
frames(c1).isSet(HEAD_BR))
                                    drawline(frames(c1).labelledPoints(HEAD_BL),
frames(c1).labelledPoints(HEAD_BR));
                                end
                                if(displayLines && frames(c1).isSet(HEAD_BL) &&
frames(c1).isSet(HEAD_F))
                                    drawline(frames(c1).labelledPoints(HEAD_BL),
frames(c1).labelledPoints(HEAD_F));

```

```

        end
        if(displayLines && frames(c1).isSet(HEAD_BR) &&
frames(c1).isSet(HEAD_F))
            drawline(frames(c1).labelledPoints(HEAD_BR),
frames(c1).labelledPoints(HEAD_F));
        end
        if(displayLines && frames(c1).isSet(HEAD_BL) &&
frames(c1).isSet(SHOULDER_L) && frames(c1).isSet(SHOULDER_R))

drawline(midpoint3d(frames(c1).labelledPoints(SHOULDER_L),
frames(c1).labelledPoints(SHOULDER_R)),
frames(c1).labelledPoints(HEAD_BL));
        end
        if(displayLines && frames(c1).isSet(HEAD_BR) &&
frames(c1).isSet(SHOULDER_L) && frames(c1).isSet(SHOULDER_R))

drawline(midpoint3d(frames(c1).labelledPoints(SHOULDER_L),
frames(c1).labelledPoints(SHOULDER_R)),
frames(c1).labelledPoints(HEAD_BR));
        end
        if(displayLines && frames(c1).isSet(HEAD_F) &&
frames(c1).isSet(SHOULDER_L) && frames(c1).isSet(SHOULDER_R))

drawline(midpoint3d(frames(c1).labelledPoints(SHOULDER_L),
frames(c1).labelledPoints(SHOULDER_R)),
frames(c1).labelledPoints(HEAD_F));
        end

    end

    % If maxMovieFrames have passed, save this movie segment to a
file and
    % start a new segment.
    colormap(bone);
    A(c1 - (Ashift - startFrame), :) = getframe(gcf);
    if c1 + startFrame - Ashift >= maxMovieFrames
        movie(A,1,100);
        saveName = strcat(movieName(1:size(movieName,2)-4),
int2str(Ashift), 'to', int2str(c1 + startFrame), '.mpg');
        mpgwrite(A,jet,saveName);
        disp(strcat('Wrote video: ', saveName));
        clear A
        Ashift = Ashift + maxMovieFrames;
    end
end

% Save remaining video images to a file.
movie(A,1,100);
saveName = strcat(movieName(1:size(movieName,2)-4), int2str(Ashift),
'to', int2str(c1 + startFrame), '.mpg');
mpgwrite(A,jet,saveName);
disp(strcat('Wrote video: ', saveName));
disp('Done writing video. ');
end

```

B.17 – midpoint3d

```

function p = midpoint3d(p1, p2)
% midpoint3d - Computes the midpoint of two points.

```

```

%
%   input args:
%           p1 - the first point
%           p2 - the second point
%
%   return vals:
%           p - the midpoint of p1 and p2

p.xval = (p1.xval + p2.xval) / 2;
p.yval = (p1.yval + p2.yval) / 2;
p.zval = (p1.zval + p2.zval) / 2;
end

```

B.18 - newMoveUnits

```

function newMoveUnits()
% newMoveUnits - This function computes the movement units for the
reach
%           action. NOTE: MUST RUN reach.m BEFORE RUNNING THIS
%           PROGRAM
%
%   input args:
%           None
%
%   return vals:
%           newdata - struct containing the number of movement
units,
%           the number of frames per reach, and the
average
%           number of movement units per frame

clear

% Loads distance, velocity, and accleration reach data from a .mat
file
data = load('output\reach\subject193018_reach_trial1vertical.mat');

% Resets movement units to 0
moveUnitsLeft = 0;
moveUnitsRight = 0;

% Plots distance, velocity, and acceleration graphs and calculates
movement
% units from the data
if(isfield(data.data, 'accLeft'))
    figure
    plot (data.data.accLeft);
    figure
    plot (data.data.distLeft);
    figure
    plot (data.data.velLeft);
    signLeft = sign(data.data.accLeft);
    for m = 1:(size(data.data.accLeft,2)-1)
        if (signLeft(m) ~= signLeft(m+1))
            moveUnitsLeft = moveUnitsLeft + 1;
        end
    end
end
%Only stores data for reaching hand
if (moveUnitsLeft ~= 0)

```

```

        newdata.moveUnitsLeft = moveUnitsLeft;
        newdata.framesLeft = size(data.data.accLeft,2);
        newdata.unitsPerFrameLeft = moveUnitsLeft /
size(data.data.accLeft,2);
    end
end

%Plots distance, velocity, and acceleration graphs and calculates
movement
%units from the data
if(isfield(data.data, 'accRight'))
    figure
    plot (data.data.accRight);
    figure
    plot (data.data.distRight);
    figure
    plot (data.data.velRight);
    signRight = sign(data.data.accRight);
    for m = 1:(size(data.data.accRight,2)-1)
        if (signRight(m) ~= signRight(m+1))
            moveUnitsRight = moveUnitsRight + 1;
        end
    end
    %Only stores data for reaching hand
    if (moveUnitsRight ~= 0)
        newdata.moveUnitsRight = moveUnitsRight;
        newdata.framesRight = size(data.data.accRight,2);
        newdata.unitsPerFrameRight = moveUnitsRight /
size(data.data.accRight,2);
    end
end

%saves the data to a .mat file
save('C:\Documents and Settings\Owner\My Documents\Dropbox\Team
AMIRA\output\newMoveUnits\subject991241_reach_trial4vertical.mat',
'newdata');
end

```

B.19 - parsingConstants

```

function parsingConstants()
% parsingConstants - This function defines values for global
variables,
% which are all enumerated values for marker array indexes.
%
%   input args:
%           None
%
%   return vals:
%           None

global HEAD_BL
global HEAD_BR
global HEAD_F
global SHOULDER_L
global SHOULDER_R
global CHEST
global HAND_L_IN
global HAND_L_OUT

```

```

global HAND_R_IN
global HAND_R_OUT
global MARKER

```

```

HEAD_BL = 1;
HEAD_BR = 2;
HEAD_F = 3;
SHOULDER_L = 4;
SHOULDER_R = 5;
CHEST = 6;
HAND_L_IN = 7;
HAND_L_OUT = 8;
HAND_R_IN = 9;
HAND_R_OUT = 10;
MARKER = 11;
end

```

B.20 - playData

```

function playData()
% playData - This function just sets up the input to runExperiment()
and
% runs it. See the comments at the top of runExperiment.m for
information
% on the parameters.
%
%   input args:
%           None
%
%   return vals:
%           None

fileName = 'data/data2011-4-29/TrackingData 2011-04-29 5.44pm.csv';
startFrame = 1;
endFrame = 4000;
labelledFrame = 111;

HEAD_BL = 1;
HEAD_BR = 2;
HEAD_F = 3;
SHOULDER_L = 4;
SHOULDER_R = 8;
CHEST = 7;
HAND_L_IN = 6;
HAND_L_OUT = 5;
HAND_R_IN = 9;
HAND_R_OUT = 10;
MARKER = 11;
points = [HEAD_BL, HEAD_BR, HEAD_F, SHOULDER_L, SHOULDER_R, CHEST,
HAND_L_IN, HAND_L_OUT, HAND_R_IN, HAND_R_OUT, MARKER];

makeMovie = 1;
useLabelledFrame = 1;
displayLines = 0;
displayLabels = 0;
labelsAreNumbers = 0;
movieName = '';
useVisualTrackingMarker = 0;

```

```

runExperiment(fileName, startFrame, endFrame, makeMovie,
useLabelledFrame, labelledFrame, points, displayLines,
displayLabels, labelsAreNumbers, movieName,
useVisualTrackingMarker);
end

```

B.21 - pointsWithinDistance

```

function points = pointsWithinDistance(p, l, distance)
% pointsWithinDistance - Returns all points in list of points within
% a distance from another point.
%
%   input args:
%       p - point with which to compare distances of points
in list
%       l - list of points
%       distance - distance threshold for accepting points
%
%   return vals:
%       points - list of points in l within distance of p

points = [];
for i=1:size(l,2)
    d = distance3d(p, l(i));
    if(d < distance)
        points = [points l(i)];
    end
end
end

```

B.22 - pointsWithingThreshold

```

function points = pointsWithinThreshold(p, l, average_d,
threshold)
% pointsWithinThreshold - Returns all points in a list of points
that are a
% certain distance from another point, with a percentage threshold.
%
%   input args:
%       p - point with which to compare distances of points
in list
%       l - list of points
%       average_d - distance for comparing points
%       threshold - percentage difference of acceptable
distance
%       error
%
%   return vals:
%       points - list of points in l about distance
average_d from
%       p

points = [];
for i=1:size(l,2)
    d = distance3d(p, l(i));
    if(d < (average_d * (1 + threshold)) && d > (average_d * (1 -
threshold)))
        points = [points l(i)];
    end
end

```

```
end
end
```

B.23 - pointWithinThreshold

```
function n = pointWithinThreshold(p, l, max_d)
% pointWithinThreshold - Returns the point in a list of points that
is
% closest to p, or -1 if no point is within a certain distance.
%
%   input args:
%       p - point with which to compare distances of points
in list
%       l - list of points
%       max_d - maximum distance for accepting points
%
%   return vals:
%       n - closest point in l to p, or -1 if there are none
within
%           max_d

n = -1;
min_d = max_d;
for i=1:size(l,2)
    d = distance3d(p, l(i));
    if(d < min_d)
        min_d = d;
        n = i;
    end
end
end
end
```

B.24 - reach

```
function reach(frames, subjectID, trialNum, isHighRisk)
% reach - This function computes the motion indicators for the reach
action
%       and puts them in a file.
%
%   input args:
%       frames - matrix containing labeled frame data
%       subjectID - ID number of the subject
%       trialNum - trial number of the action
%       isHighRisk - 0 for low-risk subject, 1 for high-risk
%
%   return vals:
%       graphs of distance, velocity, and acceleration data
%       data - struct containing all motion indicators for
the
%           action except for movement units (see
newMoveUnits.m)

global HAND_R_IN
global HAND_R_OUT
global HAND_L_IN
global HAND_L_OUT

% Defines which hand or hands are reaching (1 for reaching 0 for
not)
```



```

left = 1;
right = 0;

% Initializes arrays to store position data
handLeft = zeros(3, size(frames, 2));
handRight = zeros(3, size(frames, 2));

for i = 1:size(frames, 2)
    % Check that all necessary points are set
    if (left && frames(i).isSet(HAND_L_IN) &&
frames(i).isSet(HAND_L_OUT))
        % Get points
        mhlx = (frames(i).labelledPoints(HAND_L_IN).xval +
frames(i).labelledPoints(HAND_L_OUT).xval) / 2;
        mhly = (frames(i).labelledPoints(HAND_L_IN).yval +
frames(i).labelledPoints(HAND_L_OUT).yval) / 2;
        mhlz = (frames(i).labelledPoints(HAND_L_IN).zval +
frames(i).labelledPoints(HAND_L_OUT).zval) / 2;
        handLeft(1:3, i) = [mhlx; mhly; mhlz];
    end
    % Check that all necessary points are set
    if (right && frames(i).isSet(HAND_R_IN) &&
frames(i).isSet(HAND_R_OUT))
        % Get points
        mhrx = (frames(i).labelledPoints(HAND_R_IN).xval +
frames(i).labelledPoints(HAND_R_OUT).xval) / 2;
        mhry = (frames(i).labelledPoints(HAND_R_IN).yval +
frames(i).labelledPoints(HAND_R_OUT).yval) / 2;
        mhrz = (frames(i).labelledPoints(HAND_R_IN).zval +
frames(i).labelledPoints(HAND_R_OUT).zval) / 2;
        handRight(1:3, i) = [mhrx; mhry; mhrz];
    end
end
% Deletes missing data at the beginning of the data file
if (left && (handLeft(1,1)==0) && (handLeft(2,1)==0) &&
(handLeft(3,1)==0))
    j=1;
    while (handLeft(1,j+1)==0) && (handLeft(2,j+1)==0) &&
(handLeft(3,j+1)==0)
        j=j+1;
    end
    while (j>0)
        handLeft(:,j)=[];
        j=j-1;
    end
end
% Deletes missing data at the beginning of the data file
if (right && (handRight(1,1)==0) && (handRight(2,1)==0) &&
(handRight(3,1)==0))
    j=1;
    while (handRight(1,j+1)==0) && (handRight(2,j+1)==0) &&
(handRight(3,j+1)==0)
        j=j+1;
    end
    while (j>0)
        handRight(:,j)=[];
        j=j-1;
    end
end

```

```

end
% Deletes missing data at the end of the data file
while (right && (handRight(1,size(handRight,2))==0) &&
(handRight(2,size(handRight,2))==0) && (handRight(3,size(handRight,
2))==0))
    handRight(:,size(handRight,2))=[];
end
% Deletes missing data at the end of the data file
while (left && (handLeft(1,size(handLeft,2))==0) &&
(handLeft(2,size(handLeft,2))==0) && (handLeft(3,size(handLeft,
2))==0))
    handLeft(:,size(handLeft,2))=[];
end
% Linearly interpolates missing data in the middle of the data file
for i = 1:size(handLeft, 2)
    j = 1;
    if (left && (handLeft(1,i)==0) && (handLeft(2,i)==0) &&
(handLeft(3,i)==0))
        while (handLeft(1,i+j)==0) && (handLeft(2,i+j)==0) &&
(handLeft(3,i+j)==0)
            j=j+1;
        end
        start = handLeft(1:3,i-1);
        stop = handLeft(1:3,i+j+1);
        max = j+1;
        while (j>0)
            handLeft(1,i+j-1)=start(1)+(stop(1)-start(1))*j/max;
            handLeft(2,i+j-1)=start(2)+(stop(2)-start(2))*j/max;
            handLeft(3,i+j-1)=start(3)+(stop(3)-start(3))*j/max;
            j=j-1;
        end
    end
end
% Linearly interpolates missing data in the middle of the data file
for i = 1:size(handRight, 2)
    j=1;
    if (right && (handRight(1,i)==0) && (handRight(2,i)==0) &&
(handRight(3,i)==0))
        while (handRight(1,i+j)==0) && (handRight(2,i+j)==0) &&
(handRight(3,i+j)==0)
            j=j+1;
        end
        start = handRight(1:3,i-1);
        stop = handRight(1:3,i+j+1);
        max = j+1;
        while (j>0)
            handRight(1,i+j-1)=start(1)+(stop(1)-start(1))*j/max;
            handRight(2,i+j-1)=start(2)+(stop(2)-start(2))*j/max;
            handRight(3,i+j-1)=start(3)+(stop(3)-start(3))*j/max;
            j=j-1;
        end
    end
end
end
% Initializes arrays and variables to store distance, velocity, and
% acceleration data
distRight = zeros(1, size(handRight, 2));
derivRight = zeros(1, size(handRight, 2)-1);

```

```

derivRight2 = zeros(1, size(handRight, 2)-2);
avgVelRight = 0;
avgAccRight = 0;
progUnitsRight = 0;

% Calculates and stores distance, velocity, and acceleration data
if (right)
    max = handRight(:,size(handRight,2));
    for i = 1:size(handRight,2)
        distRight(i) = sqrt((max(1) - handRight(1,i))^2 + (max(2) -
handRight(2,i))^2 + (max(3) - handRight(3,i))^2);
    end
    figure
    plot(distRight)
    hold on
    title(strcat('Distance of Hand from Object: Subject ',
subjectID, ' Reach Trial ', trialNum));
    xlabel('Frame #');
    ylabel('Distance (m)');
    for j = 1:(size(handRight, 2)-1)
        derivRight(j) = (distRight(j+1)-distRight(j));
    end
    figure
    plot(-derivRight*100)
    hold on
    title(strcat('Velocity of Hand toward Object: Subject ',
subjectID, ' Reach Trial ', trialNum));
    xlabel('Frame #');
    ylabel('Velocity (m/s)');
    for k = 1:(size(handRight, 2)-2)
        derivRight2(k) = (derivRight(k+1)-derivRight(k));
    end
    figure
    plot(-derivRight2*10000)
    hold on
    title(strcat('Acceleration of Hand toward Object: Subject ',
subjectID, ' Reach Trial ', trialNum));
    xlabel('Frame #');
    ylabel('Acceleration (m/s^2)');
    avgVelRight = mean(derivRight)
    avgAccRight = mean(derivRight2)
    signRight = sign(derivRight);
    for m = 1:(size(derivRight,2)-1)
        if (signRight(m) ~= signRight(m+1))
            progUnitsRight = progUnitsRight + 1;
        end
    end
    progUnitsRight
end

% Initializes arrays and variables to store distance, velocity, and
% acceleration data
distLeft = zeros(1, size(handLeft, 2));
derivLeft = zeros(1, size(handLeft, 2)-1);
derivLeft2 = zeros(1, size(handLeft, 2)-2);
avgVelLeft = 0;
avgAccLeft = 0;
progUnitsLeft = 0;

```

```

% Calculates and stores distance, velocity, and acceleration data
if (left)
    max = handLeft(:,size(handLeft,2));
    for i = 1:size(handLeft,2)
        distLeft(i) = sqrt((max(1) - handLeft(1,i))^2 + (max(2) -
handLeft(2,i))^2 + (max(3) - handLeft(3,i))^2);
    end
    figure
    plot(distLeft)
    hold on
    title(strcat('Distance of Hand from Object: Subject ',
subjectID, ' Reach Trial ', trialNum));
    xlabel('Frame #');
    ylabel('Distance (m)');
    for j = 1:(size(handLeft, 2)-1)
        derivLeft(j) = (distLeft(j+1)-distLeft(j));
    end
    figure
    plot(-derivLeft*100)
    hold on
    title(strcat('Velocity of Hand toward Object: Subject ',
subjectID, ' Reach Trial ', trialNum));
    xlabel('Frame #');
    ylabel('Velocity (m/s)');
    for k = 1:(size(handLeft, 2)-2)
        derivLeft2(k) = (derivLeft(k+1)-derivLeft(k));
    end
    figure
    plot(-derivLeft2*10000)
    hold on
    title(strcat('Acceleration of Hand toward Object: Subject ',
subjectID, ' Reach Trial ', trialNum));
    xlabel('Frame #');
    ylabel('Acceleration (m/s^2)');
    avgVelLeft = mean(derivLeft)
    avgAccLeft = mean(derivLeft2)
    signLeft = sign(derivLeft);
    for m = 1:(size(derivLeft,2)-1)
        if (signLeft(m) ~= signLeft(m+1))
            progUnitsLeft = progUnitsLeft + 1;
        end
    end
    progUnitsLeft
end

% Stores data in a .mat file
data.isHighRisk = isHighRisk;
if left
data.avgVelLeft = avgVelLeft;
data.avgAccLeft = avgAccLeft;
data.distLeft = distLeft;
data.velLeft = derivLeft;
data.accLeft = derivLeft2;
data.progUnitsLeft = progUnitsLeft;
end
if right
data.avgVelRight = avgVelRight;

```

```

data.avgAccRight = avgAccRight;
data.distRight = distRight;
data.velRight = derivRight;
data.accRight = derivRight2;
data.progUnitsRight = progUnitsRight;
end

% Saves the .mat file
savefile = strcat('subject', subjectID, '_reach_trial', trialNum,
'.mat');
savedir = 'C:\Documents and Settings\Owner\My Documents\Dropbox\Team
AMIRA\output\reach\';
save(strcat(savedir, savefile), 'data');
end

```

B.25 - read

```

function frames = read(filename, startFrame, endFrame, numPts,
isNewVersion)
% read - Reads a .csv file and populates a struct with the data.
%
%   input args:
%       filename - name of file to read
%       startFrame - frame at which to start reading
%       endFrame - frame at which to stop reading
%       numPts - expected number of points to be labeled
%       isNewVersion - 1 to parse using the new save format
of
%                   TrackingTools .csv files (version 2.3.3), or 0
%                   otherwise.
%
%   return vals:
%       frames - unlabeled frame data of marker coordinates

file = fopen(filename);
str = fgets(file);

frames = [];
currentFrame = 0;

% Initialize frame struct
point.xval = 0;
point.yval = 0;
point.zval = 0;
frameStruct.rawPoints = repmat(point, numPts, 1);
frameStruct.labelledPoints = repmat(point, numPts, 1);
frameStruct.isSet = zeros(numPts);
frameStruct.numPoints = 0;
frameStruct.time = 0;

% Process file
while(str ~= -1)
    currentTerm = 0;
    frame = 0;

    % Process a single line
    while 1
        if isempty(str)
            break;

```

```

else
    [term, str] = strtok(str, ',');
    currentTerm = currentTerm + 1;

    if currentTerm == 1 && strcmp(term, 'comment')
        break;
    elseif currentTerm == 1 && strcmp(term, 'info')
        break;
    elseif currentTerm == 1 && strcmp(term, 'frame')
        frame = 1;
        [term, str] = strtok(str, ',');
        currentTerm = currentTerm + 1;
        currentFrame = str2double(term);
        if currentFrame < startFrame
            break; %skip line
        elseif currentFrame > endFrame
            return;
        end
    elseif currentTerm == 3 && frame == 1
        % This is the timestamp for the frame
        frames(currentFrame - startFrame + 1).time =
str2double(term);
    elseif currentTerm == 5
        % This is the number of points in the frame
        frames(currentFrame - startFrame + 1).numPoints =
str2double(term);
    if frames(currentFrame - startFrame + 1).numPoints
== 0
        break;
    end
    elseif currentTerm >= 6
        % This is a x, y, or z value for some point
        if ~isNewVersion
            index = floor((currentTerm - 6) / 3) + 1;
            offset = mod(currentTerm - 6, 3);
            if(offset == 0) % x
                frames(currentFrame - startFrame +
1).rawPoints(index).xval = str2double(term);
            elseif(offset == 1) % y
                frames(currentFrame - startFrame +
1).rawPoints(index).yval = str2double(term);
            else % assume z
                frames(currentFrame - startFrame +
1).rawPoints(index).zval = str2double(term);
            end
        else
            index = floor((currentTerm - 6) / 4) + 1;
            offset = mod(currentTerm - 6, 4);
            if(offset == 0) % x
                frames(currentFrame - startFrame +
1).rawPoints(index).xval = str2double(term);
            elseif(offset == 1) % y
                frames(currentFrame - startFrame +
1).rawPoints(index).yval = str2double(term);
            elseif(offset == 2) % z
                frames(currentFrame - startFrame +
1).rawPoints(index).zval = str2double(term);
            else

```

```

                                % Do nothing
                                end
                            end
                        end
                    end
                end
            end
        end
    end
    str = fgets(file);
end

```

B.26 - remove

```

function l = remove(p, l)
% remove - Removes a point from a list of points.
%
%   inputs args:
%       p - the point to remove
%       l - the list from which to remove the point
%
%   return vals:
%       l - the new list, with p removed if found

for i = 1:size(l, 2)
    if(p.xval == l(i).xval && p.yval == l(i).yval && p.zval ==
l(i).zval)
        l(i) = [];
        break;
    end
end
end
end

```

B.27 - repairLabels

```

function frames = repairLabels(frames)
% repairLabels - This function performs a second sweep of the data
after it
% has already been labeled. Now that most candidates are eliminated,
it
% will try to match the remaining labels to points using proximity.
Where
% that fails, linear interpolation is used to generate labels that
are
% missing for less and 20 frames.
%
%   input args:
%       frames - labeled frame data of marker coordinates
%
%   return vals:
%       frames - labeled frame data of marker coordinates

repairDistThreshold = 0.5;

for f = 2:size(frames,2)
    % Get unassigned points for this frame
    unassignedPoints = [];
    for i = 1:size(frames(f).rawPoints, 2)
        found = 0;
        for j = 1:size(frames(f).labelledPoints, 2)
            if frames(f).isSet(j) &&
equalPoints(frames(f).rawPoints(i), frames(f).labelledPoints(j))

```

```

        found = 1;
        break;
    end
end
if ~found
    unassignedPoints = [unassignedPoints
frames(f).rawPoints(i)];
end
end

% Assign unassigned points if there are any candidates in close
% proximity to labeled value in previous frame
for i = 1:size(frames(f).labelledPoints,2)
    if ~frames(f).isSet(i) && frames(f-1).isSet(i)
        closePoints =
pointsWithinDistance(frames(f-1).labelledPoints(i),
unassignedPoints, repairDistThreshold * 5);
        closerPoints =
pointsWithinDistance(frames(f-1).labelledPoints(i),
unassignedPoints, repairDistThreshold);
        if size(closerPoints, 2) == 1 && size(closePoints, 2) ==
1
            frames(f).isSet(i) = 1;
            frames(f).labelledPoints(i) = closePoints(1);
            remove(closePoints(1), unassignedPoints);
        end
    end
end

% Attempt linear interpolation on any remaining unlabeled points
for i = 1:size(frames(f).labelledPoints,2)
    if ~frames(f).isSet(i)
        % Find last and next time this point is labeled
        lastFrame = -1;
        nextFrame = -1;
        for lastIndex = 1:10
            if f-lastIndex < 1
                break;
            end
            if frames(f-lastIndex).isSet(i)
                lastFrame = f-lastIndex;
                break;
            end
        end
        for nextIndex = 1:10
            if f+nextIndex > size(frames,2)
                break;
            end
            if frames(f+nextIndex).isSet(i)
                nextFrame = f+nextIndex;
                break;
            end
        end
        if lastFrame ~= -1 && nextFrame ~= -1
            % Linear interpolation
            dif = nextFrame - lastFrame;
            for fixFrame = lastFrame+1:nextFrame-1

```



```

        nextRatio = (fixFrame - lastFrame) / dif;
        lastRatio = 1 - nextRatio;
        frames(fixFrame).labelledPoints(i).xval =
frames(lastFrame).labelledPoints(i).xval * lastRatio +
frames(nextFrame).labelledPoints(i).xval * nextRatio;
        frames(fixFrame).labelledPoints(i).yval =
frames(lastFrame).labelledPoints(i).yval * lastRatio +
frames(nextFrame).labelledPoints(i).yval * nextRatio;
        frames(fixFrame).labelledPoints(i).zval =
frames(lastFrame).labelledPoints(i).zval * lastRatio +
frames(nextFrame).labelledPoints(i).zval * nextRatio;
        frames(fixFrame).isSet(i) = 1;
    end
end
end
end
end
end
end

```

B.28 - runExperiment

```

function frames = runExperiment(fileName, startFrame, endFrame,
makeMovie, useLabelledFrame, labelledFrame, initPoints,
displayLines, displayLabels, labelsAreNumbers, movieName,
useVisualTrackingMarker, isNewVersion)
% runExperiment - This is the main function for labeling data and
playing
% the labeled video. It reads a .csv file into an array, accepts a
single
% manually labeled frame to label the rest of the data, and then
plays this
% data as a video and saves it.
%
%   input args:
%
%       filename - name of the file to load
%       startFrame - frame at which to start reading
%       endFrame - frame at which to stop reading
%       makeMovie - 1 to play and create a movie file, 0
otherwise
%       useLabelledFrame - 1 to use the labeled frame as
usual, or
%       0 to skip labeling and just play a video of the
unlabeled
%       points
%       labelledFrame - frame in the csv file that has been
manually labeled
%       initPoints - manual labels for a single frame
%       displayLines - 1 to display lines in the video, 0
otherwise
%       displayLabels - 1 to display labels in the video, 0
otherwise
%       labelsAreNumbers - 1 to label the points by number
instead
%       of letter in the video, 0 otherwise
%       movieName - name for saving the movie file that is
created
%       Should end with '.mpg'
%       useVisualTrackingMarker - 1 to include the extra
marker on

```

```

%             the toy (for visual tracking), 0 otherwise
%             isNewVersion: 1 if csv file was saved using new
version of
%             TrackingTools (2.3.3), 0 otherwise.
%
%   return vals:
%             frames - labeled frame data of marker coordinates

% Initialize global variables and numPoints
parsingConstants();
if useVisualTrackingMarker
    numPoints = 11;
else
    numPoints = 10;
end

% Read from .csv file
disp(['Reading from file: ', fileName]);
frames = read(fileName, startFrame, endFrame, numPoints,
isNewVersion);

% Initialize frames.isSet
for i = 1:size(frames, 2)
    for j = 1:numPoints
        frames(i).isSet(j) = 0;
    end
end

if useLabelledFrame
    % Label first frame with input
    for i = 1:numPoints
        if initPoints(i) ~= -1
            frames(labelledFrame - startFrame + 1).labelledPoints(i)
= frames(labelledFrame - startFrame + 1).rawPoints(initPoints(i));
            frames(labelledFrame - startFrame + 1).isSet(i) = 1;
        end
    end

    % Run labeling function to label data
    disp('Labelling points...');
    frames = identifyBodyPoints(frames, labelledFrame - startFrame +
1, useVisualTrackingMarker);
    frames = repairLabels(frames);
end

if makeMovie
    % Play and save video
    disp('Writing video...');
    makeVideo(frames, startFrame, displayLines, displayLabels,
labelsAreNumbers, movieName, numPoints);
end
end

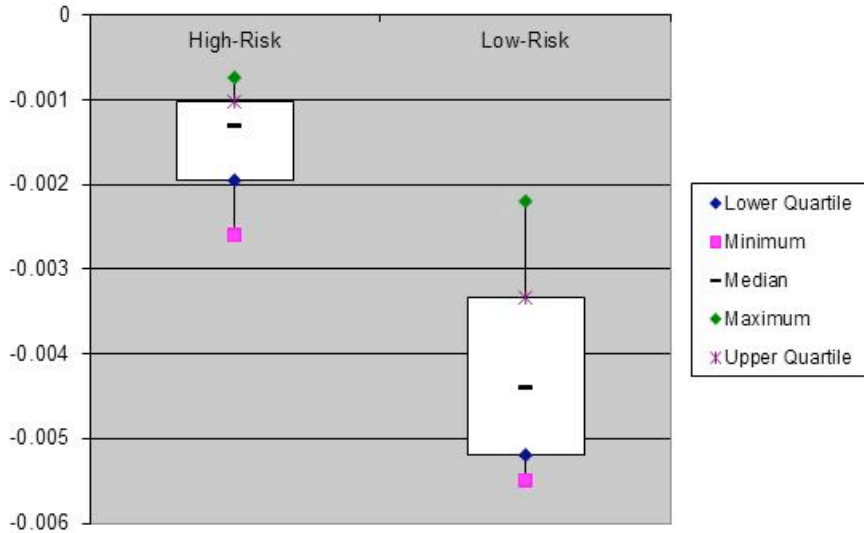
```

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Appendix C: Additional Figures and Tables

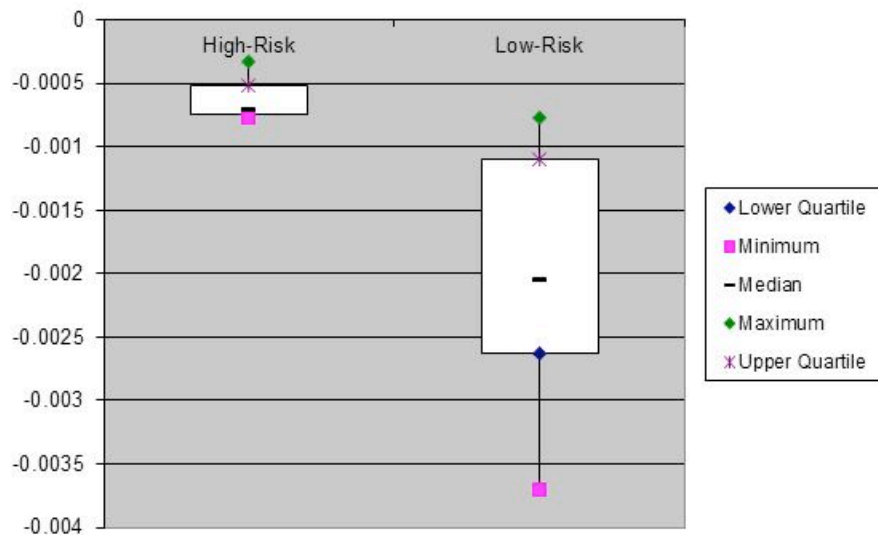
Reach-To-Grasp

Figure 38: Left hand horizontal reach, average velocity in km/s



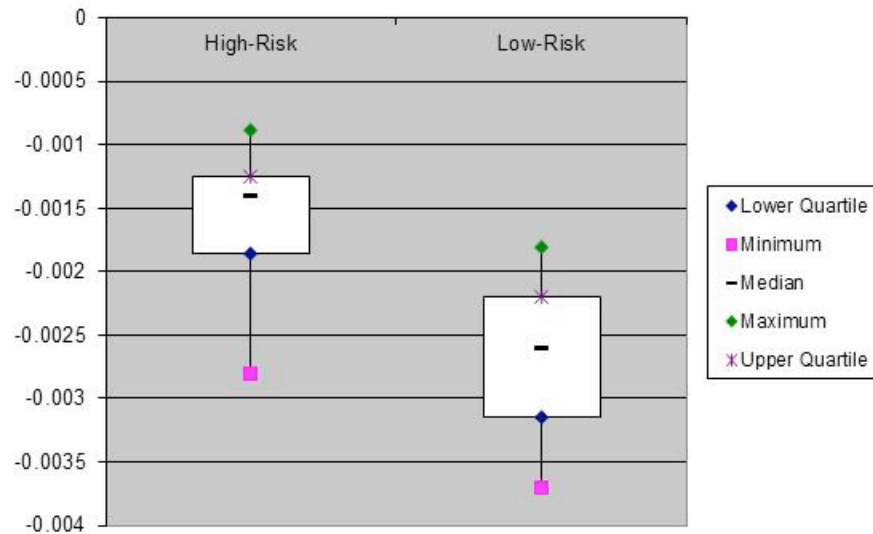
This graph shows that high-risk participants reach significantly more slowly than low-risk participants with their left hand when reaching for horizontal objects. This result is significant because the white rectangles do not overlap.

Figure 39: Right hand horizontal reach, average velocity in km/s



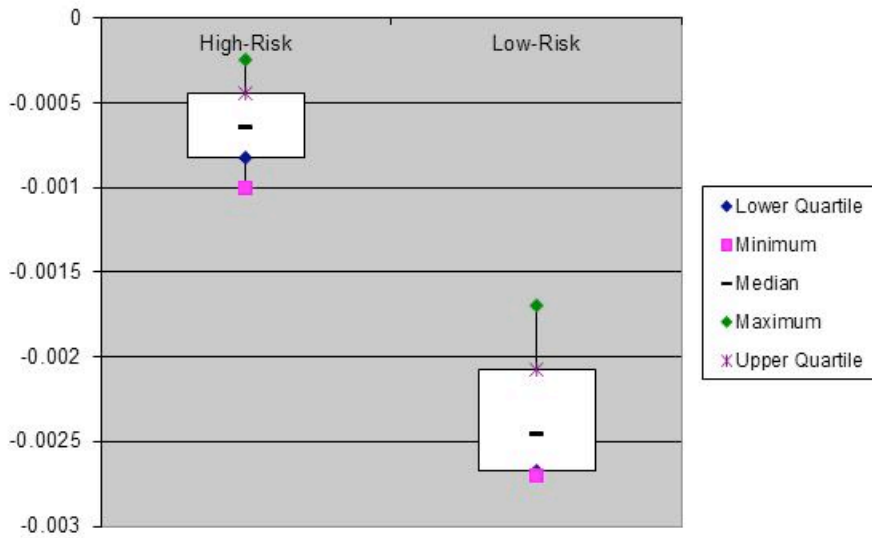
This graph shows that high-risk participants reach significantly more slowly than low-risk participants with their right hand when reaching for horizontal objects. This result is significant because the white rectangles do not overlap.

Figure 40: Left hand vertical reach, average velocity in km/s



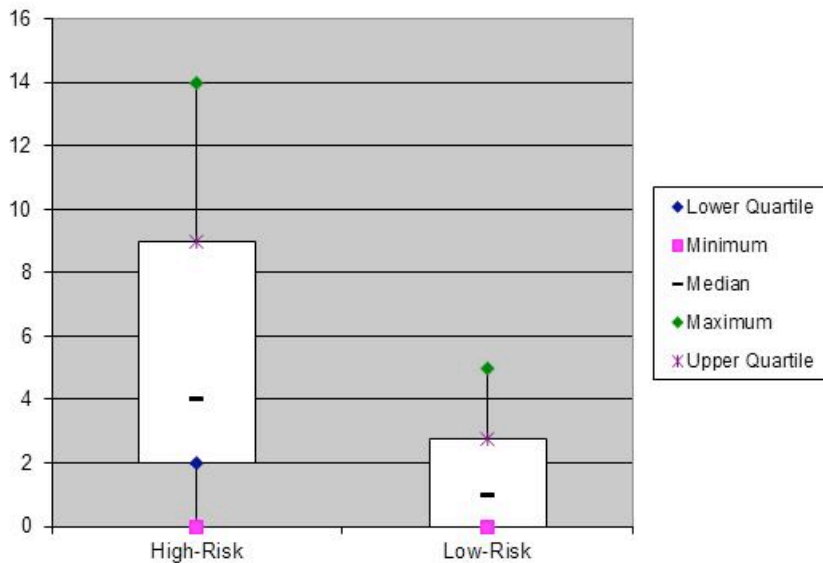
This graph shows that high-risk participants reach significantly more slowly than low-risk participants with their left hand when reaching for vertical objects. This result appears significant because the white rectangles do not overlap, but statistical analysis reveals that the difference is non-significant. It is important to remember that this graph is a visual representation, not a statistical test.

Figure 41: Right hand vertical reach, average velocity in km/s



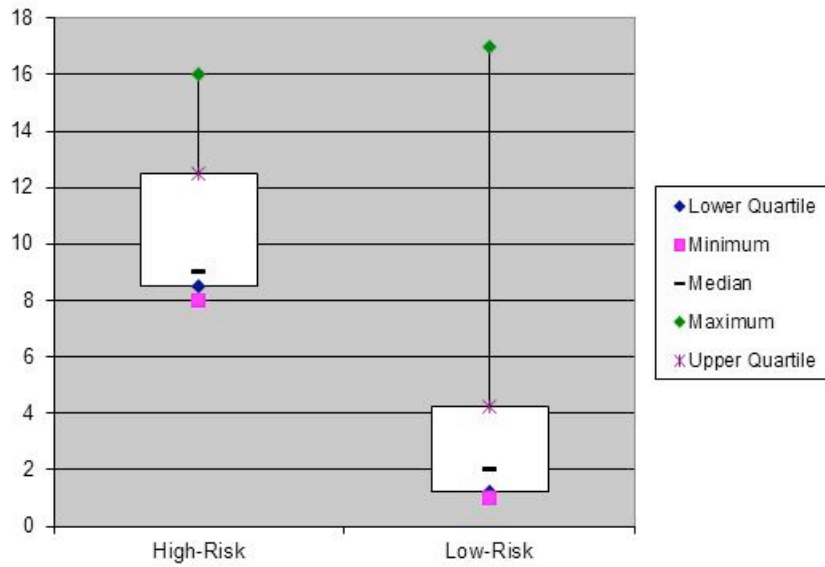
This graph shows that high-risk participants reach significantly more slowly than low-risk participants with their right hand when reaching for vertical objects. This result is significant because the white rectangles do not overlap.

Figure 42: Left hand horizontal reach, number of movement units



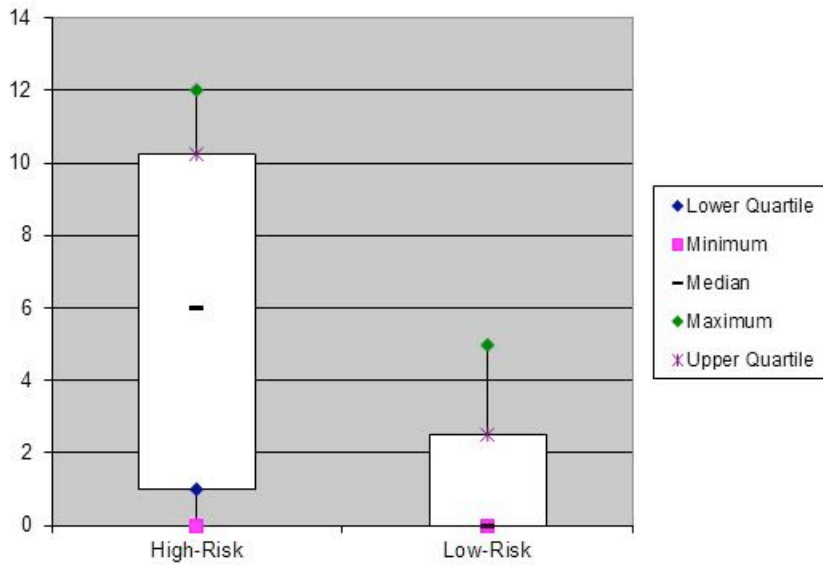
This graph shows that the high-risk and low-risk participants do not differ in their number of movement units in the left hand horizontal reach, because the white rectangles overlap.

Figure 43: Right hand horizontal reach, number of movement units



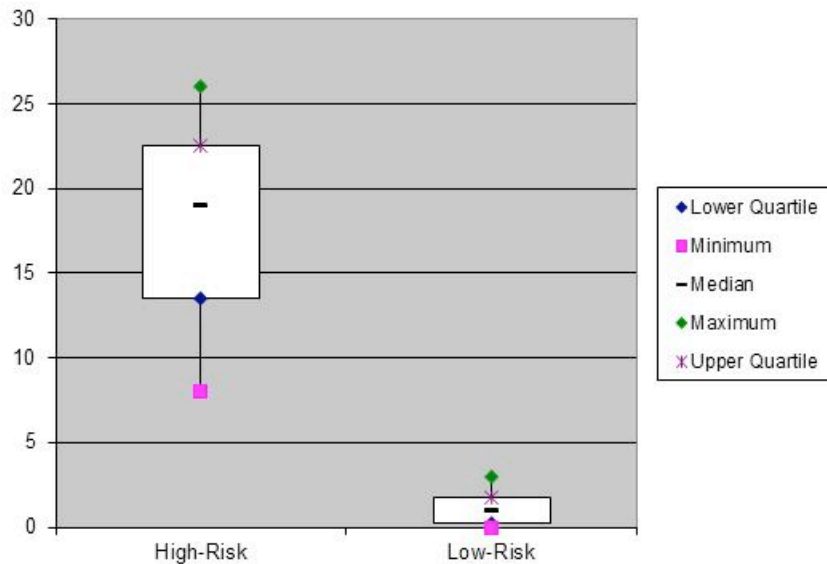
This graph shows that the high-risk and low-risk participants do not differ in their number of movement units in the left hand horizontal reach. This result appears significant because the white rectangles do not overlap, but statistical analysis reveals that the difference is non-significant. It is important to remember that this graph is a visual representation, not a statistical test.

Figure 44: Left hand vertical reach, number of movement units



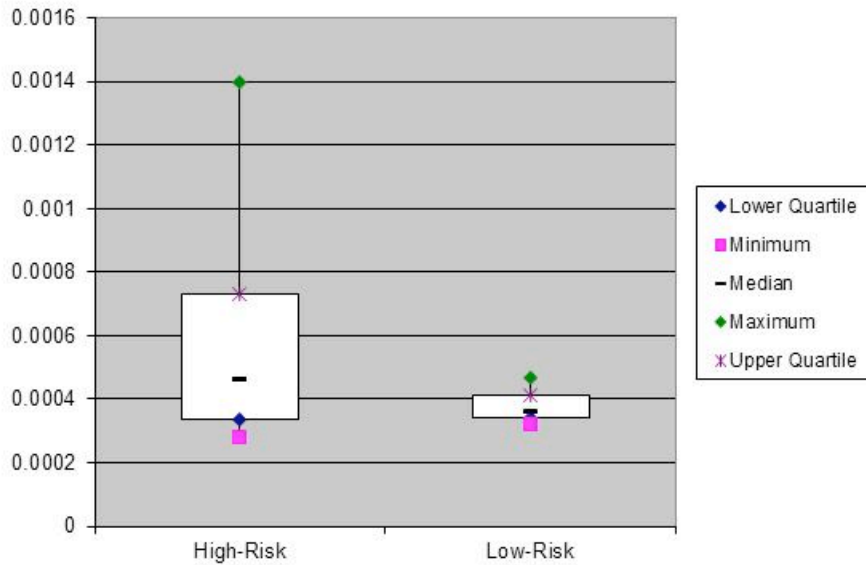
This graph shows that the high-risk and low-risk participants do not differ in their number of movement units in the left hand vertical reach, because the white rectangles overlap.

Figure 45: Right hand vertical reach, number of movement units



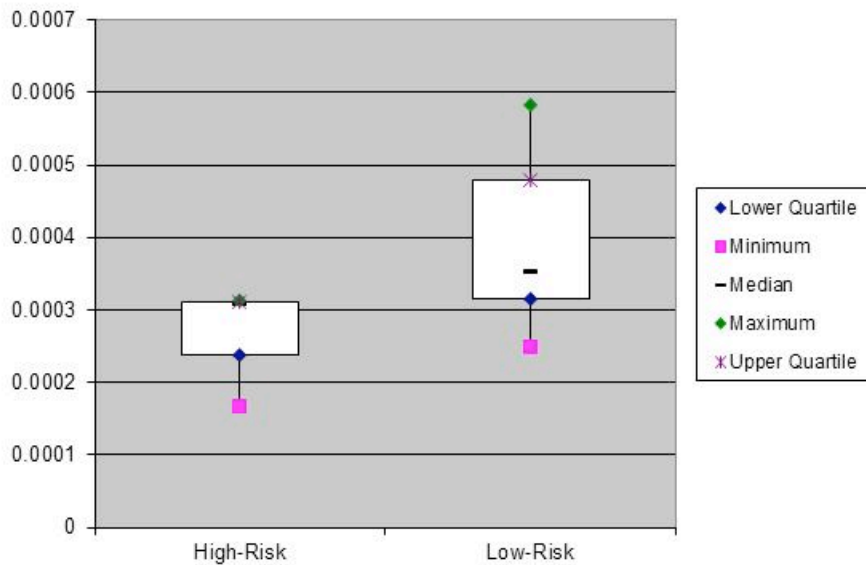
This graph shows that the high-risk participants' reaches contain significantly more movement units than low-risk participants' reaches in the right hand vertical reach, because the white rectangles do not overlap.

Figure 46: Left hand vertical reach, average acceleration in km/s^2



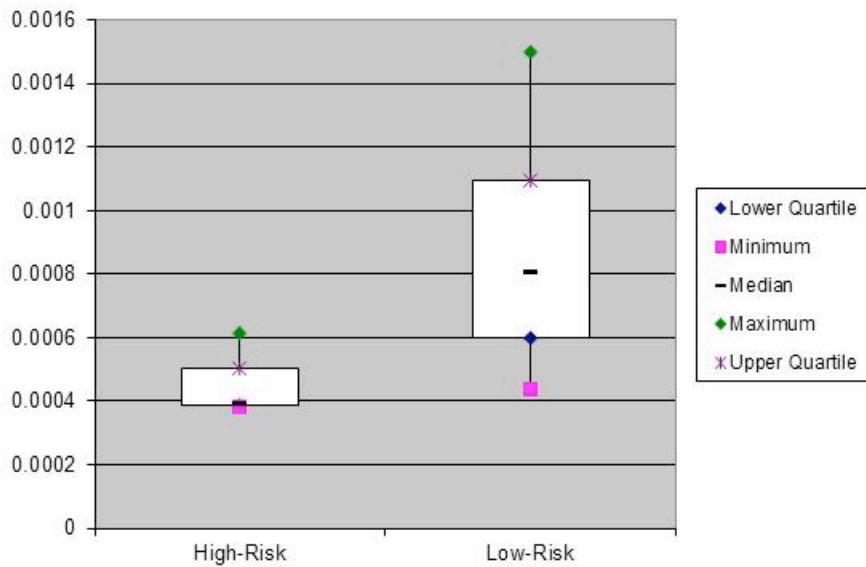
This graph shows that the high-risk participants accelerate at roughly the same rate as the low-risk participants during the left hand vertical reach, because the white rectangles overlap.

Figure 47: Right hand vertical reach, average acceleration in km/s²



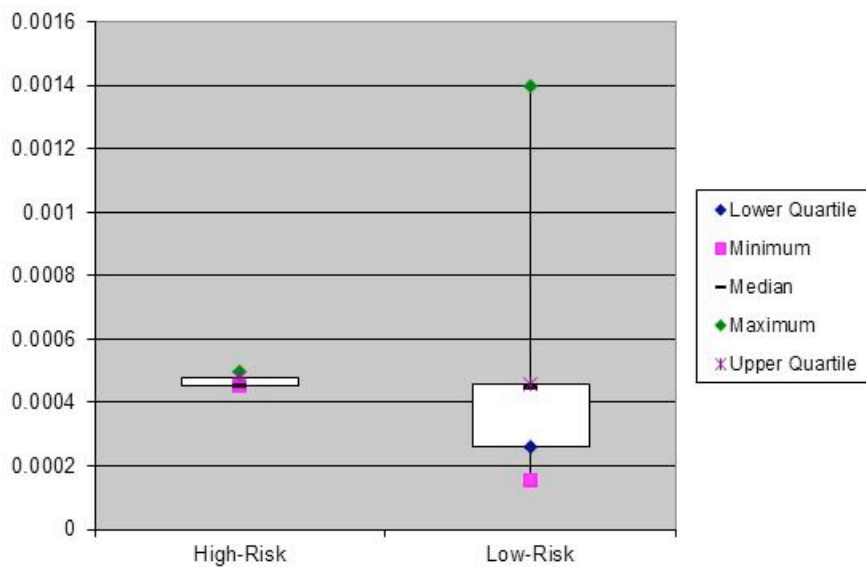
This graph shows that the high-risk participants accelerate at roughly the same rate as the low-risk participants during the right hand vertical reach, because the white rectangles overlap.

Figure 48: Left hand horizontal reach, average acceleration in km/s²



This graph shows that the high-risk participants accelerate at roughly the same rate as the low-risk participants during the left hand horizontal reach. This result appears significant because the white rectangles do not overlap, but statistical analysis reveals that the difference is non-significant. It is important to remember that this graph is a visual representation, not a statistical test.

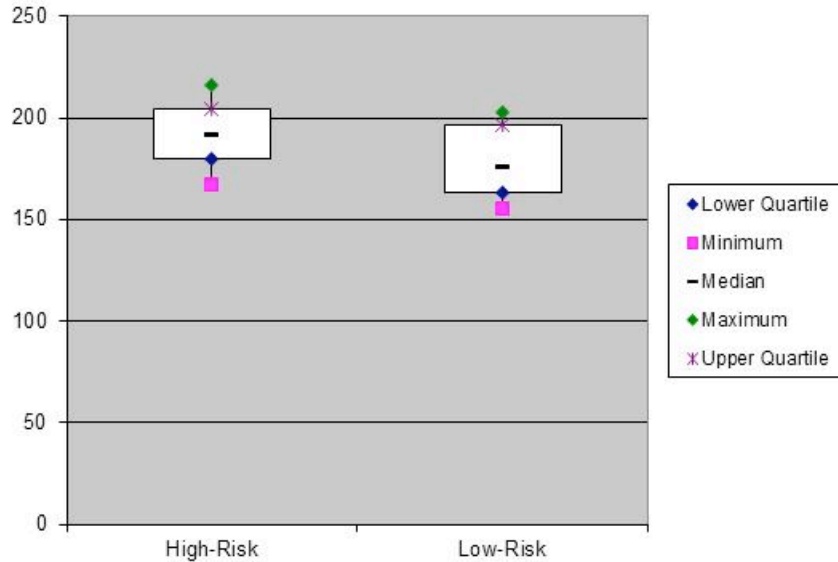
Figure 49: Right hand horizontal reach, average acceleration in km/s²



This graph shows that the high-risk participants accelerate at roughly the same rate as the low-risk participants during the right hand horizontal reach, because the white rectangles overlap.

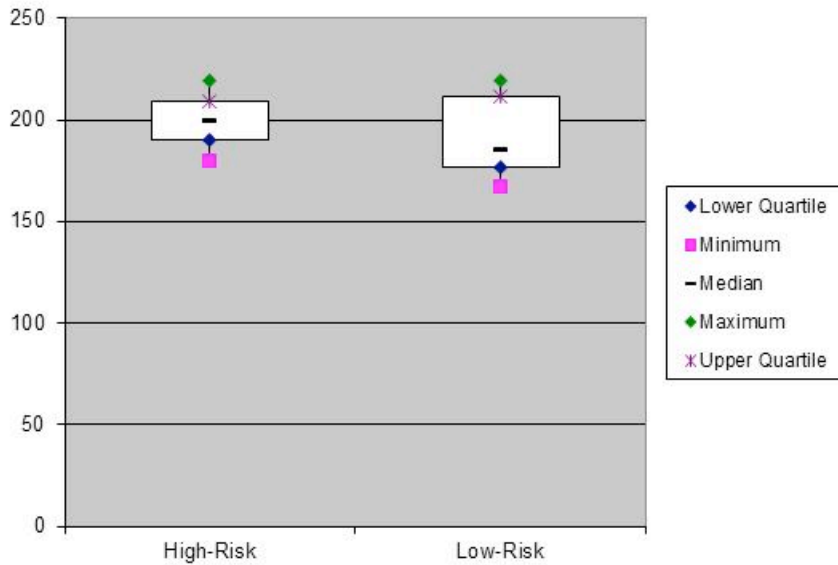
Pull-To-Sit

Figure 50: Pull-to-sit, average angle in degrees



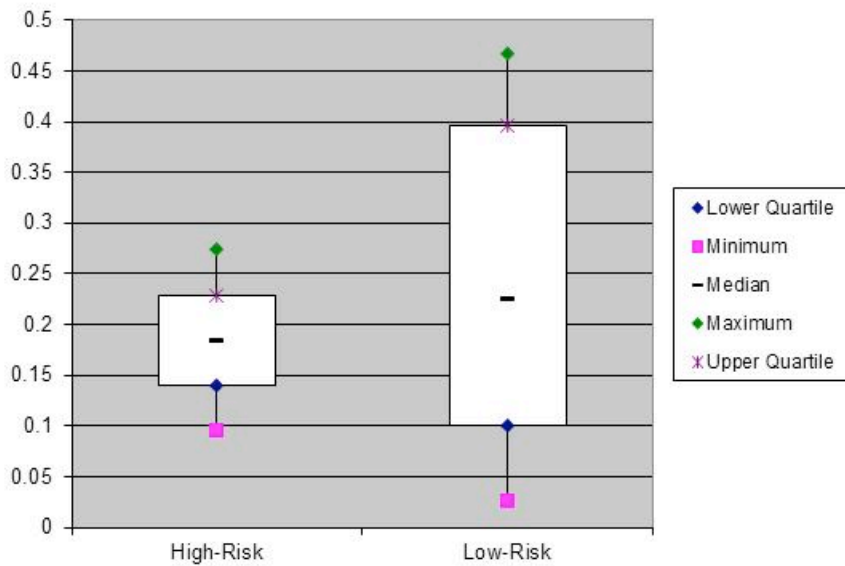
This graph shows that the high-risk participants have similar average head angles to the low-risk participants during the pull-to-sit, because the white rectangles overlap.

Figure 51: Pull-to-sit, maximum angle in degrees



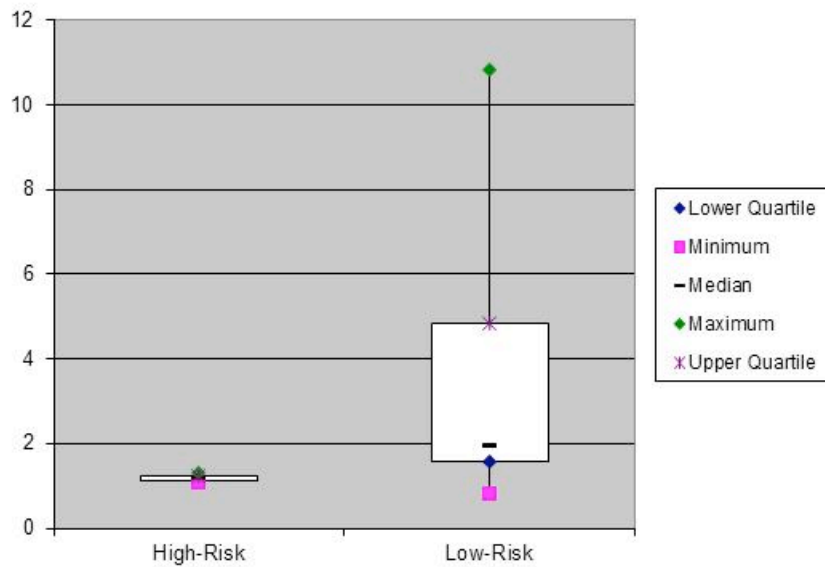
This graph shows that the high-risk participants have similar maximum head angles to the low-risk participants during the pull-to-sit, because the white rectangles overlap.

Figure 52: Pull-to-sit, maximum angle location frame number



This graph shows that the high-risk participants reach peak head angle at similar parts of the reach as the low-risk participants during the pull-to-sit, because the white rectangles overlap.

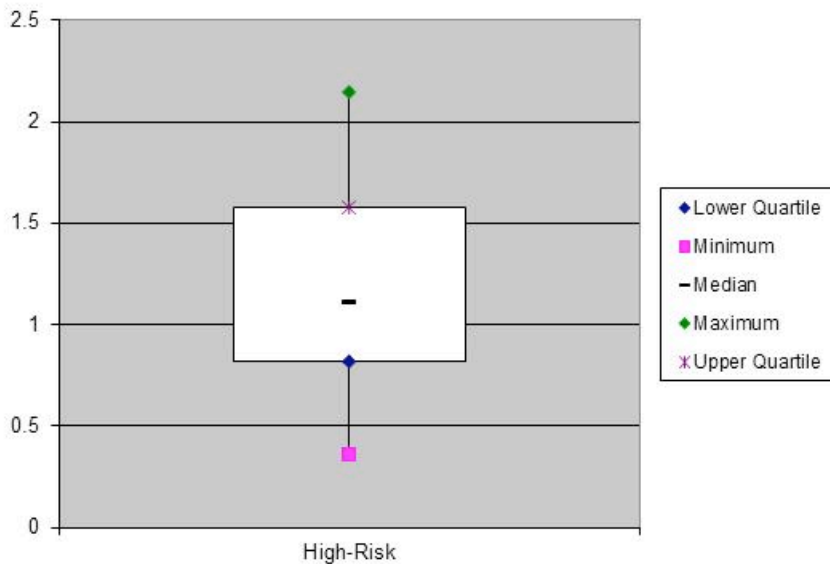
Figure 53: Pull-to-sit, maximum derivative of head angle



This graph shows that the high-risk participants have similar maximum head angle derivatives to the low-risk participants during the pull-to-sit. This result appears significant because the white rectangles do not overlap, but statistical analysis reveals that the difference is non-significant. It is important to remember that this graph is a visual representation, not a statistical test.

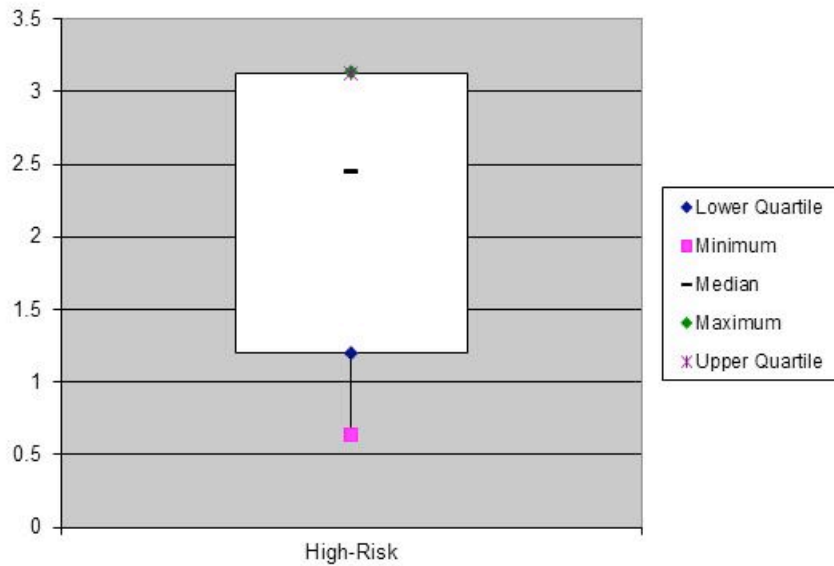
Visual Tracking

Figure 54: Visual tracking, average angle in degrees



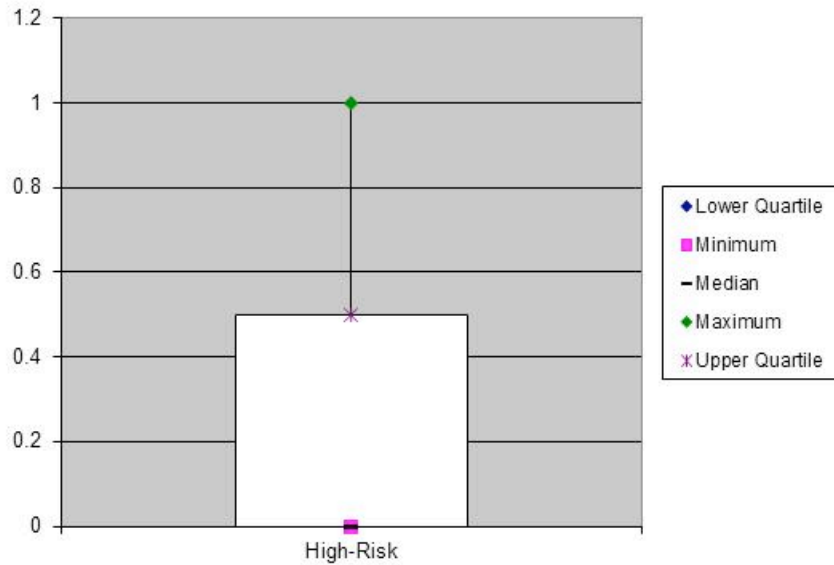
This graph shows the data trends for the average angle in the visual tracking task. There was no usable low-risk data to compare these data to, so no conclusions can be drawn.

Figure 55: Visual tracking, maximum angle in degrees



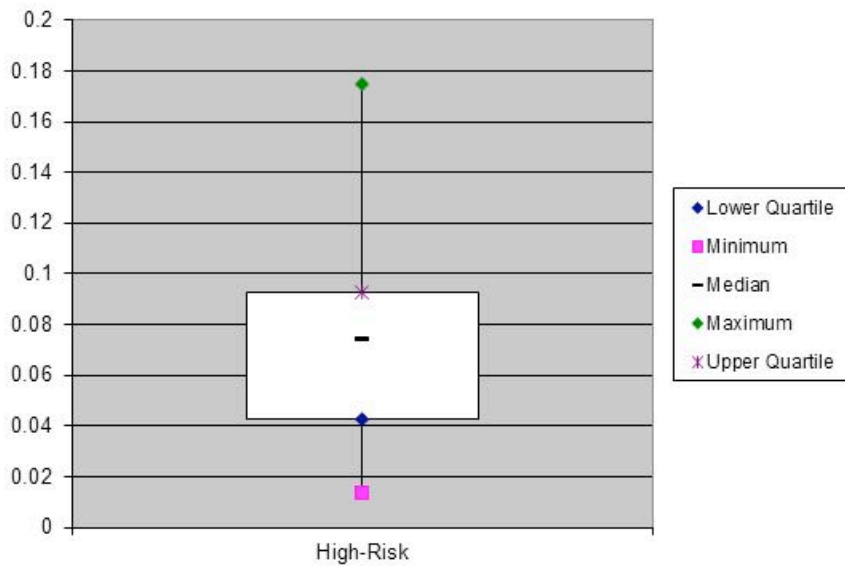
This graph shows the data trends for the maximum angle in the visual tracking task. There was no usable low-risk data to compare these data to, so no conclusions can be drawn.

Figure 56: Visual tracking, maximum angle location frame number



This graph shows the data trends for the location of the peak head angle in the visual tracking task. There was no usable low-risk data to compare these data to, so no conclusions can be drawn.

Figure 57: Visual tracking, maximum derivative of head angle



This graph shows the data trends for the maximum derivative of head angle in the visual tracking task. There was no usable low-risk data to compare these data to, so no conclusions can be drawn.

Appendix D: Movement Indicators

Pull-to-Sit	Reach-to-Grasp	Visual Tracking
Neck angle versus time	Distance versus time	Head angle versus time
Mean neck angle	Velocity versus time	Standard deviation versus time
Maximum neck angle	Acceleration versus time	Maximum angle
Neck angle derivative versus time	Average velocity	Maximum derivative
Maximum of derivative	Average acceleration	
Time ratio of maximum angle	Progression units	
	Movement units	

Glossary

Action Log – a form filled out by the Observer to denote the time of each designated action performed by the infant

Active motion capture – a technological system composed of light emitting diodes, optical cameras, and a computer software program that creates a digital representation of movement

ARENA – the software package used to calibrate the NaturalPoint OptiTrack motion capture system

Autism spectrum disorders (ASD) – a group of overlapping developmental disorders characterized by one or more of the three impairments linked to autism

Calibration rating – the level of success (poor to exceptional) calibration had in preparing the system to record motion in its capture volume accurately

Calibration wand - a three marker rod used to establish the capture volume used by the OptiTrack system

Capture volume – the space defined by a motion capture system in which it will accurately record the motion from all visible infrared-reflective points

CARD – Center for Autism and Related Disorders at the Kennedy Krieger Institute in Baltimore

Concatenate – to join values or matrices together into a single matrix **Connected components** – sets of markers that together form a rigid body as a vector or plane

Critical Points – points at which the motion of the infant changed direction significantly or stopped (first derivative on the distance vs time graph equals zero)

CSV file (comma-separated values file) – the form in which raw data was recorded by the TrackingTools system

Eigenvalues – values characteristic of a given matrix describing its equilibrium state

Eigenvectors – vectors characteristic of a given matrix describing its equilibrium state

Error rate – the incidence of errors in data analysis

Exclusionary criteria – criteria that, if met, would disqualify an infant from participation in the study to maintain the integrity of the research

F-test – a statistical test used to differentiate true positives from false positives

Head angle – the angle between the direction of the head and that of the toy

Head-lag – a motion indicator defined as the rate of change in the angle between a vector perpendicular to the plane formed by three markers on the head and the plane formed by two shoulder markers and chest markers

High-risk for ASD – refers to a participant that has a sibling with autism spectrum disorders (a member of our experimental group)

HIPAA (Health Insurance Portability and Accountability Act) – this act consisted of a set of guidelines followed to ensure privacy of the participants and their families

Inertial motion capture - a technological system composed of gyroscope sensors that translate movement into a three dimensional digital representation of the movement

Likert Scale – a scale on which the infant cooperation is rated from 1 to 5

Low-risk for ASD – refers to a participant that does not have a sibling with autism spectrum disorders (a member of our control group)

Marker – a small sphere covered in material reflecting infrared light used to mark a specific location that can be recorded by a motion capture system as it moves through 3D space

MATLAB (matrix laboratory) – a high-level language and numerical computing environment used to develop data analysis software for this motion capture application

Modularity – the ability of system components to be interchanged for new ones without compromising the integrity of data collection

Motion capture – the act of recording motion using the exact location of specific points in 3D space

Motion capture hardware – the cameras, computer, and suit components of a motion capture system

Motion capture software – the algorithm used to record and analyze the motion of markers in 3D space

Motion capture suit – a garment placed on a participant with attached markers to be used as part of a motion capture system

Motion capture system – a system used to create a digital representation of movement

Motion indicator - a defined movement believed to be indicative of ASD

Movement unit – a motion indicator consisting of discrete divisions in the reaching task separated by points of inflection on the distance versus time graph or points where the acceleration equals zero

MPEG file (moving pictures experts group file) – a universal video file format

Neck angle – the angle measured between the vector from midpoint between the chest markers to the midpoint between the shoulder markers; and the vector from midpoint between the chest markers and the midpoint between the rear head markers

Observation Sheet – a form filled out by the Observer to provide a Likert Scale rating for each task and to record any deviations from the established protocol

OptiTrack motion capture system – a passive motion capture system produced by NaturalPoint. The OptiTrack system used in this study consisted of 12 infrared cameras (0.3 megapixel resolution at 100 Hz) placed around a room used to track the motion of infrared reflective markers placed on an object

Passive motion capture – a technological system composed of infrared cameras and computer software that creates digital models of movement. Passive systems rely on infrared light reflective markers, which the camera is able to track through three dimensional space

PCA (Principal Component Analysis) – a dimensionality reduction technique to determine the contribution of each component vector to the whole input vector

Percent frames ignored – a measure of the number of unusable frames in a trial used to determine the integrity of the data

Postural control - a task in which the infant is provided with cylindrical objects of identical size and different mass

Progression Unit – a motion indicator consisting of discrete divisions in the reaching task separated by points at which the motion is stopped or changes direction significantly (first derivative on the distance vs time graph equals zero)

Proximity labeling technique – a technique for labeling points using the principle that points can only move a certain distance between frames

Pull-to-sit - a task in which the infant is pulled from a supine to seated position by the researcher

P-value – a statistical measure of significance of data

Reach-to-grasp - a task in which the infant is encouraged to reach for a cylindrical object in both a horizontal and vertical orientation

Reach velocity – a motion indicator consisting of the velocity of the wrist markers in a reaching task

Supine position – a body orientation in which one is lying on one's back facing upwards

Tracking Tools – a software package used to record the position data from IR markers

Visual-tracking - a task in which the infant is encouraged to watch an object as it is moved through a 180 degree arc positioned in the center of their field of vision

Welch's T-test – a statistical test used to determine statistical significance of the data

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