Autism, New Music Technologies and Cognition

by

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B.A. Music Therapy
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Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
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Abstract

Central coherence accounts of autism have shown dysfunction in the processing of local versus global information that may be the source of symptoms in social behavior, communication and repetitive behavior. An application was developed to measure cognitive abilities in central coherence tasks as part of a music composition task. The application was evaluated in collaboration with the Spotlight Program, an interdisciplinary social pragmatics program for children with Asperger's syndrome. This research indicates that it is possible to embed cognitive measure as part of a novel music application. Implications for current treatment interventions, and longitudinal experimentation designs are presented.

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My family.

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CHAPTER ONE

Introduction and Motivation

Music affects us in ways that are more direct and substantial than just about any other stimulus. We don't know why. We can only begin to understand how. And yet, when one considers the simple physicality of it all, pressure waves impinging themselves on a flap of skin, music really seems like nothing at all. Somewhere between sound waves and the fullness of our relationships to music as an art form lie the pieces of a complex neurological phenomenon. At the interaction of music, neurobiology, diverse cognitive processes, and disease, is the opportunity to construct technological solutions that can simultaneously leverage findings from all of these areas, and direct an experience that can be maximally therapeutic, creative, adaptable, and scalable.

In this thesis I describe software applications developed to provide individuals with autism the opportunity to participate in musical tasks that directly engage cognitive areas known to be dysfunctional in the population. The result is a technology that can describe cognitive features of the music creation process with implications for innovative treatments and cognition research.

Chapter two reviews the relevant literature to describe the current state of autism, music therapy, and cognitive training.

Chapter three outlines initial research from other treatment domains, their design criteria, flaws, and implications for the current research.

Chapter four introduces the applications developed to specifically address the use of music as a clinical intervention for autism.

Chapter five presents experimental data used to justify the design decisions made in the development of the current system. This chapter also introduces results from the use of these tools by children with autism spectrum disorder.

Lastly, Chapter six concludes the thesis by summarizing the interdisciplinary issues addressed throughout the document, in addition to outlining future work and experimentation.

1.1 An Opportunity in Music Therapy and Autism

The field of music therapy has been struggling to define itself for well over fifty years. For diseases as diverse as schizophrenia [Gold et al., 2005], dementia [Sherratt et al., 2004], dyslexia [Overy, 2003], aphasia [Belin et al., 1996], Parkinson's disease [McIntosh et al., 1997] and a host of other psychiatric and physical illnesses, music therapists have attempted to document specific clinical benefit through music interventions. Unfortunately, there are few objective reviews of music interventions from outside of the music therapy community. Existing third party reviews raise issues regarding flawed methodology, limited scope, and unjustified evaluation criteria [Vink et al., 2004]. Even more problematic is the lack of scientific understanding as to how or why music is effective as a treatment. The critical research question holding the field of music therapy back is: how does one scientifically quantify what is taking place, cognitively, physically, and creatively during music making in the clinical environment; and what tools, techniques and activities might be developed to best leverage these findings?

The ideal population for this line of work is the autistic population because of the prevalence of social features, cognitive deficits, and proposed neurobiological antecedents. Novel technologies and applications have the potential make a unique contribution to a disease with a complex description across multiple domains.

Individuals suffering from the autistic spectrum of disorders display a range of symptoms in social interaction, communication, and repetitive patterns of behavior [American Psychiatric Association, 2000]. Early work in autism outlined these symptoms within a "theory of mind [Peterson, 2005, Baron-Cohen et al., 1985]. Autistic individuals have difficulty understanding that other people maintain separate minds with independent beliefs, needs and intentions. As a result, they cannot evaluate the effect of their behaviors on others in the social environment.

Prior work in music intervention for individuals with autism, although largely unscientific, typically utilizes the social component of music making to encourage meaningful social participation [Kaplan and Steele, 2005]. Autistic individuals are isolated, falling into patterns of repetitive and often inappropriate or self-damaging behavior. The goal of a music performance and composition system is to draw the autistic individual into an interaction where they can safely and slowly develop an understanding of role, cause and effect in social situations. In a traditional music therapy intervention, this is done through improvised music. An autistic individual is encouraged to explore some instrument, and eventually participate in a group music making process. The therapist works to create opportunities within the music interaction for the autistic individual to exchange musical content with other members of the group. The entire process serves to establish social roles, and an awareness of other members musical intentions and needs. Over time, the therapist assesses whether or not the autistic individual has changed behavior outside of the group [Whipple, 2004].

Our application will do much more than this. In addition to outlining a system to improve social behaviors through group music making, this research develops a system for quantifying the cognitive development of the group participants over time. Furthermore, the cognitive measures of interest are derived from recent theoretical advances in the underpinnings of autism, which has been an elusive disease from the neurobiological standpoint. By incorporating our applications into longitudinal music treatments, it becomes feasible to augment the social sphere of current music intervention practices with quantifiable data.

With cognitive measurement taking place during a longitudinal behavioral music intervention, it is possible to construct a system that adapts itself over time to better address the performance needs of the autistic user. The goal of developing the tools outlined in this thesis is to construct a framework for quantifiable cognitive measure as part of musical intervention that can be extended to adaptive treatment systems.

The underlying neurobiological mechanisms of autism are only recently emerging, representing a major growth area for the field of neuroscience and its link to pathological cognition and behavior. A survey of neuropathological findings suggests that autism is not seated in a single neural region of deficit [Bachevalier and Loveland, 2005]. The disease is challenging to intervention designers because of the broad spectrum of symptoms and underlying neural correlates observed between subjects. A multimodal intervention in the form of a musical application is uniquely appropriate to examine the contribution of various aspects of cognition to the exhibited behavior of an individual with autism. Music requires diverse cognitive resources, including: visual-spatial processing, memory, motor programming, auditory and verbal processing. Some scientists feel that music is the premier stimulus for investigating cognitive processes and their distribution across the brain [Zatorre and McGill, 2005]. Our application will provide a musical and technical framework for simultaneously investigating multiple domains of cognition, their relationship to symptomatic behaviors and subsequent improvement over those behaviors.

1.2 A Technological Solution

A technological solution is the most appropriate for this problem because a custom interface is implied to break the music interaction into manageable pieces on which we can perform quantifiable analysis and still maintain a music interaction with clinical substance. A music solution is the most appropriate because, despite the problems facing the field of music therapy, music remains a uniquely encouraging, supportive, nonthreatening, and creative means to explore substantial illness [Standley, 1986]. Also, musical interventions can be complementary alternatives for patients with whom traditional therapies do not work.

CHAPTER TWO
Literature Review

2.1 Autism Spectrum Disorders

The term autism originates with Kanner, who in 1943 described a series of children who were thought to have unique behavior in an attempt to establish affective and interpersonal contact. Soon after, Hans Asperger described similar behavioral symptomology, decoupled from abnormal intelligence[Asperger, 1944]. Although only in 1994 was Asperger's syndrome distinguished from autism in a large field trial that brought Asperger's within the context of pervasive developmental disorders. Asperger's remains distinct from autism but within the autistic spectrum of diagnoses[Volkmar et al., 1994]. Today it is understood that autism is a complex series of diseases, all with distinct cognitive, etiological, and neuropathological features. In this review, unless otherwise specified, autism refers to the entire spectrum of the disease, including subtypes such as Asperger's syndrome and pervasive developmental disorder-not otherwise specified.

Research towards a better understanding of the genetic component of autism is an area of intensive focus. Monozygotic twin studies have shown a significant concordance rate, between 36% and 72%[Folstein and Rutter, 1977, Folstein and Piven, 1991], compared to 3% concordance in dizygotic twins [Lauritsen and Ewald, 2001]. One attractive hypothesis, based on evidence from twin studies, is that the genetic susceptibility to autism is inherited by a multifactorial threshold model, where several loci and a differential threshold of susceptibility between females and males would explain various features of twin study data, including the increased penetrance of the disease in males[Bailey et al., 1995]. However, it is more likely that a contribution of environmental factors influence genetic susceptibility over an otherwise heterogenous method of inheritance.

More research is needed to determine what environmental factors influence susceptibility to autism and to what extent. There is an association between various perinatal risk factors and autism[Larsson et al., 2005, Wilkerson et al., 2002]. Although, contradictory reviews contend that there is no specific or consistent link between pre-, peri-, or neonatal complications and autism[Nelson, 1991]. Additionally, pre-natal, and peri-natal risk factors are difficult to analyze independently of whether they impinge upon an already compromised infant, or combine with genetic predisposition to lead to developmental disturbances during growth.

There is also a strong association between the psychiatric history of parents and autism. These findings are, of course, sensitive to comparison group, method of evaluating psychiatric illness, and are generally inconsistent[Yirmiya and Shaked, 2005].

Sensorimotor deficits are common in autistic individuals. 37% to 95% exhibit hand or finger mannerisms, body rocking, or unusual posturing[Lord, 1995, Rogers et al., 1996]. Furthermore, sensory processing abnormalities have been reported for 37% to 95% of individuals, with varying levels of granularity, from preoccupation with certain sensory objects, over or under-responsiveness to stimuli from the environment, or paradoxical responses to sensory stimuli[Kientz and Dunn, 1997].

Examining metabolic deficiencies and toxicologic studies of autism have not currently been useful for diagnosis or treatment. In 1998, a group of researchers proposed an influential theory associating autism and other pervasive developmental disorders with measles, mumps and rubella vaccination [Wakefield et al., 1998]. The primary assumption of the proposed association is that thimerosal, a preservative containing mercury frequently used in measles, mumps and rubella vaccinations, leads to mercury toxicity in a subset of the population, with genetic predisposition to autism [Bernard et al., 2001]. The popularity of this theory has led to numerous advocacy groups demanding that thimersol be removed from vaccination. The Institute of Medicine, prompted by the Centers for Disease Control and Prevention as well as the National Institute of Health, established an independent expert committee to evaluate the evidence pertaining to measles, mumps, and rubella vaccinations, thimerosal, autism and other implicated neurodevelopmental disorders. The Institute of Medicine has released several reports that emphasize no causal association between measles, mumps, and rubella vaccinations or thimersol and autism[Institute of Medicine, 2004, Stratton et al., 2001]. Large sample statistical analysis comparing children vaccinated with thimerosal versus thimerosol-free conditions, found no causal relationship between thimerosal and autism[Hviid et al., 2003]. Other arguments such as incidence of autism paralleling the introduction of mercurial vacciantions, and symptoms of autism being similar to symptoms of mercury poisoning, have also been refuted [Nelson and Bauman, 2003].

2.1.1 Neuropathology

Neuropathological findings for autism exist on several different levels, from functional to structural and cellular level abnormalities. Many autistic patients have abnormal EEG readings. Additionally, the autistic population exhibits a high incidence of various types of epileptic seizures[Kim et al., 2006, Muñoz-Yunta et al., 2003, Pavone et al., 2004], where the association is stronger in adulthood[Howlin et al., 2004].

One hypothesis is that the neurobiological underpinnings of the disease pertain to myelination processes. The majority of the autistic population (56%) has antibodies to myelin basic protein compared to a mere 9% of control subjects[Singh et al., 1993]. Over-expression of myelin basic protein antibody may lead to disfunctions in myelination or myelin function.

During the 1970s and 1980s, computerized axial tomography scans were ordered as standard assessments of children diagnosed with autism. The results of those assessments seemed to indicate a wide range of structural abnormalities in the neuroanatomy of subjects with autism. However, Damasio and colleagues showed that structural differences were attributable to the coexistence of other anatomical disorders, separate from autism[Damasio et al., 1980]. By pre-screening subjects for abnormalities in addition to autism, autistic individuals do not display significant structural abnormalities in CT and MRI [Filipek, 1999].

Neuroanatmoical research has evolved since diagnostic CT. High resolution functional and structural MRI have elucidated various areas of functional and structural abnormality in autistic individuals. However, it has been unclear whether observed abnormalities in regions as diverse as the cerebellum, associative cortex, limbic system, and basal ganglia are necessary correlates for autism. A brief examination of findings in the cerebellum will highlight the nature of dilemma typical to neuropathologic research in autism.

In human and animal studies, the cerebellum has been linked to many areas of primary interest to autism pathology, including motivation, joint attention shifting[Courchesne et al., 1994a], motor learning, social interaction, visual-spatial processing[Townsend et al., 1999], and processing of sensory information[Gao et al., 1996]. Reduced Purkinje cell density in the neocerebellum has been reported in several studies with small sample sizes both, with, and without accompanying mental retardation and epilepsy[Courchesne et al., 1994b]. Postnatal cerebellar insult has been ruled out as a cause for the observed structural differences, suggesting that cerebllar abnormalities develop at some point in early stages of embryonic development[Kemper and Bauman, 1993]. The sequence in which cerebellar Purkinje cell abnormalities propagate is the key to understanding how the system could relate to behavioral abnormalities, and is currently under investigation. Some cerebllum researchers contend that the reported amount of Purkinje cell decrease is unlikely during early embryonic development based on the normal development of the cerebellum. There is an increased likelihood of developing other diseases related to atypical Purkinje distribution if it took place at such an early stage of development [Harding and Copp, 1997]. The observed cerebellar abnormalities may not be pathologically significant for autism. The cascade of social deficits are unlikely to be seated in cerebellum dysfunction and it is unclear whether or not the cerebellar findings are epiphenomena or part of broader cortex abnormalities.

There has been a great deal of speculation regarding the role of “mirror neurons” and autism. The mirror neuron system was first described in primates as dedicated activation in ventral premotor cortex to the performance of certain motor actions, and the observation of similar actions in other primates. Optimistic researchers and journalists have proposed that mirror neurons may be involved in systems for social learning through observation and imitation in humans. Furthermore, researchers have suggested that mirror neurons may have a role in disorders of social learning in autistic individuals[Williams et al., 2001]. The difficulty with mirror neuron hypotheses of autism are that mirror systems largely pertain to motor imitation and observation of physical activities by biological actors[Tai et al., 2004]. It may not be suitable to attribute complex social deficits to mirror neuron dysfunction even if motor observation and imitation abnormalities indirectly relate to social learning. Mirror neuron activation differences for observation and imitation of"“emotional facial expressions” have been reported in autistic subjects[Dapretto et al., 2006]. However, it is likely that limbic system abnormalities in the autistic population supersede disorders in emotional processing when considering the definitive role of limbic structures in processing emotion and feeling. If mirror systems are proposed to project emotional and socially relevant information to the limbic system, researchers will need to better display how disorders in mirror neurons effect a much more significant locus of emotional and social processing. Otherwise, it is impossible to distinguish whether activation differences in mirror neurons, upstream from limbic abnormalities, are causally related to the limbic pathology typically observed in autistic individuals, or merely artifact to a a primarily limbic disorder in emotional perception.

2.1.2 Perception and Cognition

Research into the neuroscience of autism has not yet produced results that are useful for treatment or prevention of the disease. Because of the lack of findings as to the biological underpinnings of a complex disease with primarily social symptoms, research in autism has experienced a renaissance for the investigation of higher-order cognitive functions. Observed neuropsychological deficits within the autistic population are complex, as they deal with abstract processes such as reasoning, integration, abstraction, interpretation and reciprocity in areas as diverse as language, various forms of memory, executive functioning, auditory processing, social perception, mathematics, and other cognitive domains. There are no consistent biological markers for autism, requiring that screening focus on behavior and the complex cognitive functions that underly behavior. An outline of an autism diagnostic algorithm, seen in Figure 2-1, indicates a precedence for social and observational measures of neurological laboratory investigation.

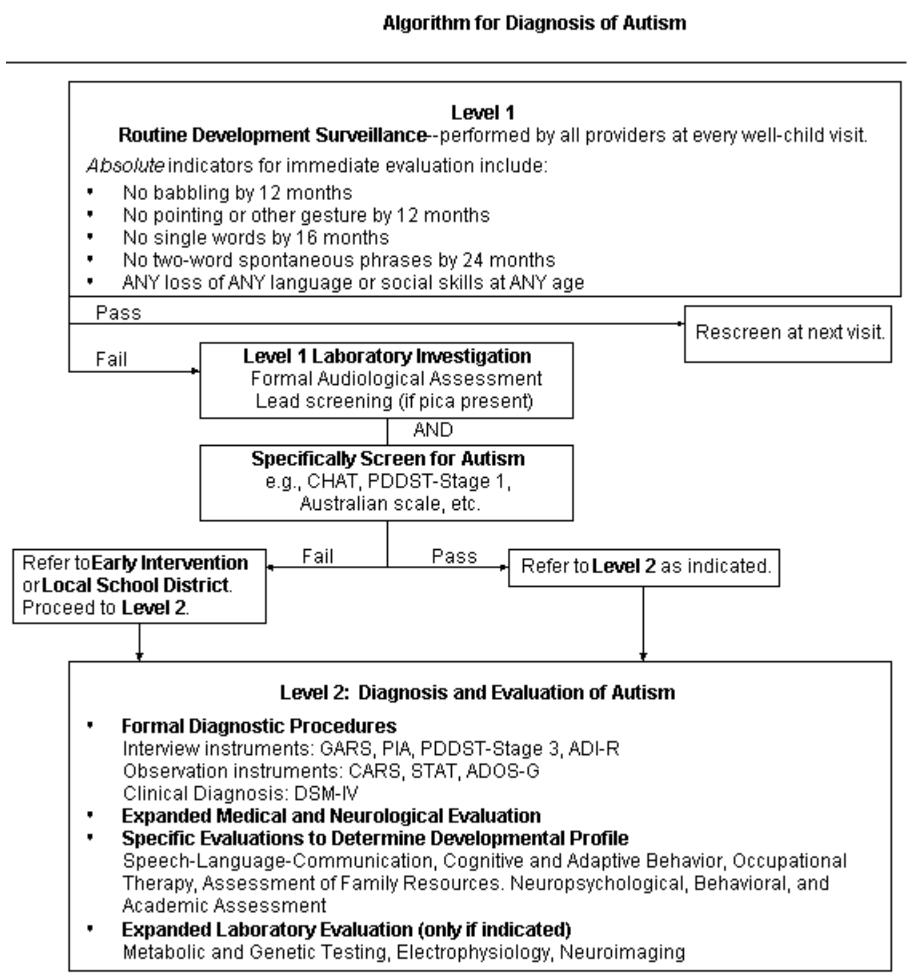

Figure 2-1: **An algorithm for autism diagnosis, from [Filipek et al., 2000]**

Autistic individuals show a characteristic performance on intellectual tests, modulated by full scale IQ. Unlike mental retardation, which requires an IQ below 70 and concurrent deficits in adaptive function, autistic individuals have poorer adaptive function then would be explainable by concurrence with the IQ[Volkmar et al., 1993].

Theory of mind accounts of autism have been the predominant driving force behind education and treatment practices for the disease. Theory of mind is the understanding that other individuals have "minds" of their own, and are therefore capable of independently developing their own needs, accounts of a situation, and beliefs. Theory of Mind was attributed to autism in the mid-eighties [Baron-Cohen et al., 1985]. It is best described by the Sally-Ann task. In the Sally-Ann task the experimentor describes a situation where two people, Sally and Ann walk up to a box. There is a stone outside of the box. Sally, in front of Ann, places the stone into the box. Then, Ann goes away. While Ann is away, Sally removes the stone from the box, and places it into her pocket. Ann returns to the scene. The experimentor then asks where Ann will look for the stone. An individual with intact Theory of Mind will distinguish between Ann and Sally as independent entities that are individually capable of referencing the experiences they have had to form opinions. The answer will be that Ann will look in the box. An individual without Theory of Mind will think that Ann will look in the pocket. The theory as it relates to autism is that individuals with autism do not have intact Theory of Mind, giving rise to their unique spectrum of social disorders which are based in an inability to evaluate others as independent actors with their own intentions, beliefs and needs.

Researchers have attempted to validate the Theory of Mind account by positing that a mechanism for Theory of Mind processing may exist somewhere in the brain[Leslie et al., 2004]. However, due to a lack of a biologically plausible model to support the processing of theory of mind, other cognitive and neuropsychological theories are currently being developed. One of these theories examines an executive function process known as central coherence[Frith, 1989].

Central Coherence

Weak central coherence is a processing bias for detail-focused, local information, at the expense of meaning or gestalt. It is a deficit in the ability to organize a whole object from its constituent parts.

A canonical example of weak central coherence exists in the visual-spatial domain. The Wechsler Block Design Task requires an individual to reconstruct a geometric pattern from a series of small wooden blocks. The six faces of the blocks have different patterns. Also, the blocks can each only fill in one small part of the parent geometric shape (see Figure 2-2). The user must mentally break the given geometric target into its constituent parts, find those parts on the faces of the smaller blocks, and reassemble the target image from the

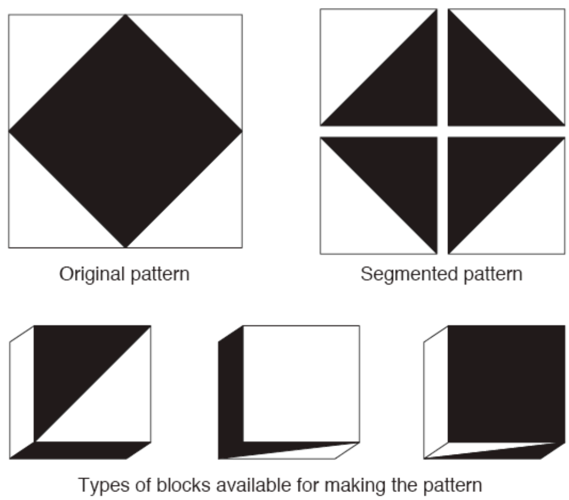

Figure 2-2: **Anatomy of a block design task, from [Happé, 1999]**

blocks. One reason the task is difficult is because we naturally resist the mental breaking of the parent block into its constituent elements. Therefore, if you pre-segment the target design, individuals take less time to complete the task. However, autistic individuals not only outperform control subjects, but also gain little benefit from the pre-segmented condition. This seems to indicate that the autistic population may have a proclivity for pre-segmenting to find local features in complex visual-spatial contexts [Shah and Frith, 1993]. The benefit of a central coherence account of autism is that it serves not only to explain areas where autistic individuals underperform but also those where they better than control subjects[Happé, 1999].

In a recent review published by the founders of the central coherence hypothesis, 58 experimental group studies were summarized in which weak central coherence in autistic spectrum disorders was investigated. Of the 58 studies reviewed, 43 focused on visualspatial processing in embedded figures tasks (n=6), block design tasks (n=3), hierarchical figures (n=6), visual illusions (n=3), drawing tasks (n=6), face perception tasks (n=5), and other tasks (n=14). Of the 9 verbal central coherence studies reviewed, the focus was predominantly on homograph reading (n=5), among other verbal memory tests (n=4). Lastly, auditory central coherence (n=6) focused on pitch perception (n=4), rather than music (n=1) and psychoacoustics (n=1) [Happé and Frith, 2006].

Realistically, weak central coherence is not likely to give rise to the cascade of developmental features exhibited in autism spectrum disorders. However, central coherence provides a useful set of measures for examining resolute cognitive processes that potentially relate to complex social behaviors.

The few studies related to auditory central coherence are of particular interest. It is generally understood that individuals with autism show improved performance over control subjects in many sensory perception and discrimination tasks, particularly in the visual-spatial domain. The limited work in reproducing central coherence findings in other perceptual domains is a limiting factor of the hypothesis. A deficit in something as broadly defined as a discrepancy in local versus global hierarchical processing should be evidenced in multiple domains.

The autistic population displays exceptional abilities in the processing of non-hierarchically organized auditory stimuli in a variety of experimental contexts. In pitch discrimination tasks, autistic individuals are able to make same-different evaluations better than controls. In categorization tasks, autistic individuals are better able to compare groups of tones to one another and classify them as relatively high or low[Bonnel et al., 2003, Heaton, 2003]. There are subtle differences for the memory requirements of categorization and discrimination tasks. In general, these findings support a large body of research showing increased abilities of autistic individuals for the perception of low-level stimuli. The term *low-level* is appropriate because these studies utilize stimuli that do not make substantial demands on associative and cortical centers of processing for the individual to extract their essential features.

The progression towards hierarchically organized auditory sequences from simple discrimination and categorization tasks allows one to begin describing cognition for music. Because music is replete with opportunities for form and structure, investigation of its handling by the autistic population is an ideal area to make inquires as to the validity of the weak central coherence models, and differential processing of hierarchical organization in general.

Mottron and colleagues set out to examine hierarchical musical processing in non-savant individuals with high-functioning autism or Asberger's syndrome (n=13) versus age and IQ matched controls. Their stimuli where nine note melodies that intrinsically provide the framework of a hierarchical system. The researches contend that pitches independently have a local feature in their frequency or pitch height. Combinations of pitches yield intervalic relationships, which are local in the sense that they form relationships to one another, and not to the melody as a whole. Lastly, groups of melodies form a melodic contour, which is taken as the global context. These three levels of pitch relationships form a hierarchy of organization for the perceived auditory object.

12 target melodies were presented to subjects in two conditions, transposed and not transposed. A transposed melody moves each note in the target melody a set number of pitch intervals. Within the transposed/not-transposed conditions, there were several other modifications. Melodies were either altered to be contour-preserved or contour-violated alternatives. A contour preserved melody has a single note altered, but changed in a way that the direction of the melody stays the same with regard to the notes neighboring the altered

note. Contour-violated melodies change the direction relationship between the altered note and the neighboring notes.

Subjects were given two sets of trials. In the first set, non-transposed target melodies were used. Subjects would receive a melody, followed by a contour violated, contour preserved, or unaltered melody. A set consisted of 24 unaltered melodies, 12 contour violated and 12 contour un-violated melodies. In the second set of tests, the target melody was transposed, and the tested on melodies were untransposed, with the same distribution of unaltered and altered presentations.

The researchers reported a significant advantage for the autistic group over the control group for descrimination of contour-preserved melodies in the non-transposed condition. Additionally, the researchers found that both groups were impaired in transposed descrimination, and both groups performed better when melodies were contour-violated compared to when they were contour preserved. This study does not provide any evidence of local processing distinction in the clinical group. The researchers contend that the contour-preserved non-transposed condition allows the opportunity for the autistic population to more efficiently use local pitch cues to discriminate. The experiment at no time evaluated efficiency between local and global factors. Therefore, it is not reasonable to assume that efficiency of local processing was a factor in the observed beneift. Furthermore, there were opportunities across conditions for subjects to differentially rely on local processing efficiency, that were not borne out in results [Mottron et al., 2000].

One difficulty of this study is that the understanding of a note, once presented within the context of a melody, is inseparable from its global features. The gradient from pitch to interval, and finally melodic contour is underspecified as to the variable contribution of local and global factors of the various levels of hierarchy. For instance, to what extent is an interval relationship processed independently for its "local" characteristic over the fact that it is heard within a melodic context? It is nearly impossible to distinguish between local versus global processing, as the two are not mutually exclusive of one another. It is unclear to what extent an individual, when presented with a musical melody, will differentially balance the consideration of a note's local versus global features as a baseline, let alone in disorder. In contrast, fMRI research has delineated between differential processing of pitch contour and pitch value[Griffiths, 2003]. Different centers of processing for hierarchical features of pitch exist along an ascending neural pathway dedicated to acoustic perception. At each level of the pathway, more information is represented and perceived. Additionally, the features of a given melody are not processed independently of one another at any point in the auditory pathway.

Mottron and colleagues examine the contribution of local and global factors to same-different evaluations of melodies in flux. By either preserving or violating the melodic contour, the researchers are able to suppress the contribution of global cues to same-different judgement for a given melody. Likewise, by transposing a melody, the local pitch values are altered while the global contour remains the same. Although this does not contend with definitive issues as to the independence of local versus global features of an object, it does allow the researchers to investigate processing differences when local versus global contribution to same-different discrimination is decreased or remains the same.

A new method is required for accessing local and global features of complex auditory stimuli such that the differential contribution of local versus global features can be parsed out in statistical analysis.

2.2 Music Therapy

What passion cannot music raise and quell!
When Jubal struck the corded shell,
His list'ning brethren stood around
And wond'ring, on their faces fell
To worship that celestial sound:
Less than a god they thought there could not dwell
Within the hollow of that shell
That spoke so sweetly and so well.
What passion cannot music raise and quell!
-excerpt from, A song for St. Cecelia's Day, 1687
John Dryden (1631-1700)

Music affects us in ways that are both profound and deeply embedded in basic mechanisms of neural and physical science. It is unique as a stimulus, in the sense that an evocative chord or melody has the power to elicit complicated and powerful memories, associations, and patterns of thinking. And yet, when ones considers the mechanisms at work, sound as pressure waves propagating through the air, impinging on nothing more than a flap of living tissue moving back of and forth in your ear, music really seems like nothing special at all.

However, in the path between mechanism and manifestation, the music response touches upon a multitude of cognitive platforms. Music has antecedents in language [[[ref]], motor representation, memory processing, emotional processing, hierarchical structure organization, and many other domains of cognitive function[Zatorre and McGill, 2005]. This multistoried representation of music across the brain results in a stimulus that can be re-appropriated for therapeutic purposes with diverse patient populations. If a neurological disorder presents functional deficits in areas where some component of music is processed, a music therapy can be designed to target the area in question.

The rapidly developing understanding of music and its therapeutic use as a neuroscientific phenomena is in it infancy. Currently, the larger body of music therapists practice a behavioral type of therapy that relies heavily on social components to create relationships between therapist and client. The relationship is then utilized to various treatment ends. The national organization defines music therapy as:

> "the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program.
>
> Music Therapy is an established health profession in which music is used within a therapeutic relationship to address physical, emotional, cognitive, and social needs of individuals. After assessing the strengths and needs of each client, the qualified music therapist provides the indicated treatment including creating, singing, moving to, and/or listening to music. Through musical involvement in the therapeutic context, clients' abilities are strengthened and transferred to other areas of their lives. Music therapy also provides avenues for communication that can be helpful to those who find it difficult to express themselves in words. Research in music therapy supports its effectiveness in many areas such as: overall physical rehabilitation and facilitating movement, increasing people's motivation to become engaged in their treatment, providing emotional support for clients and their families, and providing an outlet for expression of feelings.[American Music Therapy Association, 2006]"

The emphasis is clearly on motivation, expression, engagement, and emotional support, within the framework of a "therapeutic relationship". These are not necessarily scientific criteria, nor do they have to be. Music therapy has reached countless individuals, as certified professionals garner relationships that have the strength to impact incredible pathologies. However, for a treatment that is robust, scalable, and causally related to the stimuli chosen and the treatment decisions made, something more is necessary.

The rest of this chapter focuses on the history of music therapy, treatment goals and objectives of standard practices, the anatomy of a music therapy session, the design limitations inherent to this session environment, and a detailed examination of the work regarding music therapy for individuals with autism spectrum disorders.

2.2.1 A Brief History of Music Therapy

The National Association for Music Therapy was founded in 1950. Since that time, the population of music therapists practicing in the United States has grown considerably. In 2005, the American Music Therapy Association reported 3697 members[American Music Therapy Association, 2005]. The board certification process is recognized by the National Commission on Certifying Agencies. Quality assurance of practicing members is evaluated by the national organization according to standards of practice, a code of ethics, a peer review system, a judicial review board, and ethics board.

In recent years, the practice of music therapy has been consistently moving in the direction of neuroscience and cognition. For instance, in 2005 The Fondazione Mariani Onlus organized the second global conference in The Neurosciences and Music. The seven session focus covered ethology and evolution, music and language, mental representations, developmental aspects and the impact of music on education, neurological disorder and music, music performance, and emotion in music. The conference was highly attended by researchers and therapists alike, with 380 participants in total, and an accompanying publication covering evolution and music, music and language, neurological disorders and music, music performance, emotion and music, and music therapy[Avanzini et al., 2005]. This showing of therapists in academic communities is far from uncommon. In a struggle to find insurance reimbursement for clinical services delivered, therapists are looking for the fundamentals responsible for the efficacy exhibited in their therapeutic practices. They are turning to neuroscience and cognition.

Another example of this trend is the Institute for Music and Neurologic Function, an affiliate of the Bronx, New York, based sub-acute rehabilitation network, the Beth Abraham Family of Health Services, founded in 1995. The Institute's mission is as follows:

> Through the scientific explorations of music and the brain, the Institute for Music and Neurologic Function seeks to establish new knowledge and develop more effective therapies which awaken, stimulate and heal through the extraordinary power of music.
>
> The Institute for Music and Neurologic Function, a nonprofit 501(c)(3) agency, was founded by the Beth Abraham Family of Health Services in 1995 to restore, maintain and improve people's physical, emotional and neurologic functioning through the systematic use of music. The Institute offers a variety of resources:
>
> - Expertise in treating neurological conditioned diseases such as stroke, trauma, dementia, Alzheimer's, Parkinson's and other diseases and conditions.
> - Vast clinical experience applying techniques in a large, diverse residential population.
> - Internationally and nationally recognized training programs in music therapy.
>
> The Institute for Music and Neurologic Function prescribes a music treatment with the assumption that a neurological disorder

> requires a music therapy tailored to address the neurologic components of that disorder. In contrast to the American Music Therapy Association's definition of services, the emphasis is on evidence based neurologic measures rather than behavioral and humanistic practices. Current research in music and neurologic function describes how music is firmly based in complex neural processes. Suitable neurologically based music therapies should be possible. Unfortunately, it is unclear how music is meant to target areas of neuropathy based only on "scientific exploration of music and the brain[Institute for Music and Neurologic Function, 2006]".

Despite the rapidly growing understanding of how music is distributed across the brain, a group such as the Institute for Music and Neurologic Function is limited by a lack of tools to link the neuroscience of music to clinical treatment practices. When contemporary music therapists are faced with a patient, they are not necessarily in a position to employ those scientific findings to ensure targeting of the brain areas in deficit. Although acknowledgment of scientific exploration in overlapping areas is an accomplishment in standards of practice, it is not sufficient to ensure causality in the music therapies conducted.

To conclude this section, two promising areas of music therapy where clinicians are most likely to develop treatment practices connecting neuroscience and clinical work, are Melodic Intonation Therapy and Rhythmic Entrainment Therapy.

The foundation of rhythmic entrainment is that motor systems in the brain can acquire external time-ordered stimuli to assist in the synchronization of neuronal ensemble firing related to the success of time-ordered physical movement. A disease resulting in a loss of appropriate synchronization is Parkinson's disease. In Parkinson's disease, cell degeneration in basal ganglia leads to a decrease in dopamine, a neuromodulatory chemical that assists in time-ordered neuron synchrony in a cortical-basal ganglia loop. The basal-cortical loop is essential to smooth and organized motor function. Following a decrease in dopamine, motor synapses get locked in a pattern of firing that gives rise to Parkinson's pathology. The result is rigidity, slowness of movement, tremors, and difficulty with balance that can be extremely debilitating.

Various researchers have shown that the introduction of a repetitive auditory stimulus provides a cue that is sufficient to assist in the rehabilitation of motor function for patient's with Parkinson's disease[Thaut et al., 1996, Del Olmo et al., 2006]. The presumption is that the auditory stimulus inhibits the locking response of the dopamine-deficient cortical-basal loop.

Also pertaining to motor rehabilitation, stroke research is another area where promising results have been shown with auditory stimulation aiding in motor organization. Time-orderded auditory stimulation in several different stroke conditions increases oscillatory synchrony within the motor cortex[Thaut et al., 1997] In general, oscillator models are used to describe the motor control effects on the synchronized firing of neuronal ensembles. The difference between stroke and Parkinson's disease is that the cellular substrate of Parkinson's is relatively consistent in the neurochemical domain, whereas neural trauma induced by stroke related scarring yields cell death with a wide variability in scope of damage and whether that damage is localized to a single or multiple brain areas. This difference is pertinent to the extension of neuroscience findings to clinical practice. In Parkinson's disease, auditory entrainment research directly implies novel forms of treatment. In stroke rehabilitation, between subject differences in neural insult due to stroke shifts the paradigm such that novel treatment practices in auditory motor synchronization and plasticity imply new neuroscience research.

Differences aside, between increased oscillatory synchronization and basal-cortical inhibition, the entrainment of the motor system to external auditory stimuli is a promising line of research and clinical practice where the auditory stimulus is shown to impinge directly on the neural systems in deficit, allowing auditory research to make the transition directly into clinical practice. This is not music. However, as the use of auditory stimuli become standardized clinical practice for motor rehabilitation, researchers may endeavor to expand the stimuli in question to incorporate even more hierarchically organized auditory stimuli in the form of music. The variable contribution of complex auditory stimuli, such as music, in an auditory rehabilitation paradigm could potentially bridge the issues in granularity between music and evidence based practices rooted in basic neuroscience of auditory perception and motor organization.

Melodic Intonation Therapy is the practice by which aphasic patients, who have lost the ability to speak due to stroke, traumatic brain injury or a host of other neurological disorders, are rehabilitated to sing, and eventually, speak again. The rehabilitation is intensive, requiring the subject to attempt to vocalize using the melodic framework of a multiple pitch phrase for several hours per day. The hypothesis underlying melodic intonation therapy is that music processing has sufficient overlap with damaged language areas, but dedicated processing of its own, that can be acquired by the brain as it struggles to re-organize new circuitry for the production of syntax. The neuroscience behind this phenomenon is embedded in the plasticity of auditory pathways for language and syntax.

Melodic Intonation therapy is one of the music therapies that frequently gets described in popular literature, as it is one of those phenomena that is shocking to behold. The patient, when told to speak the lyrics to 'Happy Birthday', stuttering and perseverating on a single vowel sound, like /O/, and then transforming to be able to sing the entire song with minimal affliction, is a staggering sight.

2.2.2 Music Therapy and Autism

An interview was conducted with music therapist Krystal Demaine, M.Ed., MT-BC, NMT, to determine the structure of a typical music therapy session serving individuals on the autism spectrum. Her specialty is music therapy practice with autistic individuals, although she is qualified to serve a diverse set of populations. Krystal sees her work fitting somewhere in between identifying loci of neurologic deficit, constructing tasks to address those areas of deficit, and a more holistic approach, defining the needs of the individual in terms of social context, music making abilities, broad communication goals, needs of the family, and quality of life concerns.

As an example of treatment goals and objectives for an individual with autism in music therapy, with symptoms in communication, social interaction, and repetitive behavior, the individual may have accompanying goals in articulation, sensory integration, use of expressive language, and attention to task. Session objectives drawn from Krystal's practice would typically incorporate measurable tasks such as: will sing a complete song of eight words with music accompaniment in two of four trials, will remain on-task in verbal or instrumental call and response for up to thirty minutes, and will maintain 100% participation in singing tasks up to two minutes in duration. In a different case, a lower functioning, blind wheelchair bound, nonverbal individual on the spectrum displayed goals to develop motor coordination, communication and sensory integration. Session objectives where to display social awareness at 75% for four out of four sessions, to independently initiate reaching, grasping and holding of instrument related object for thirty seconds, and to display self-awareness through movement for four out of four sessions.

Session structure for low functioning individuals on the spectrum usually begin with a greeting song to orient the subject to the day, and the time for music therapy. Songs focusing on motor and sensory issues from Krystal's practice may focus on self-awareness and the causal relationships between what the individual can use and what the result is. For instance, game-like songs might involve call and response where an individual identifies, "I brought this to music, I brought that, Im gonna use this to do this..." and the accompanying acting out of the musical action in the context of accompanying instrumental and vocal support from the therapist. Songs focusing on vocal facility employ motor entrainment principles as outlined in recent research by Thault and others. Rhythmic speech, rhyhmic vocal call and response, and turn taking principles are employed to structure speech in time, and incorporate as much motor coordination for speech production as possible. Sessions typically end with a *goodbye song* to provide closure. Session format can also be flexible, in an attempt to allow the subject to specify concerted choices over the direction of material and interaction as part of their social development.

Music therapy assessment and documentation procedures often utilize standardized reimbursement codes that are identical to the codes employed in traditional therapies, such as occupational and physical therapy. For instance, the International Classification of Diseases, 9th edition(ICD-9), and the American Medical Association's Current Procedural Terminology (CPT Codes) provide diagnostic definitions and descriptions of practice . In the CPT codes, even where the implementation of services involve the use of music as a tool, codes are are used to describe the mechanisms employed by subjects to achieve clinically resolute goals and objectives. Figure 2-3 shows a small section of a session invoice for a low-functioning individual with autism, working on speech and motor objectives. The documentation of services does not change just because the musical interaction utilized to address the proposed goal areas is strongly social.

7/28/06	1 Units # 92506 1 Unit # 97110 1 Unit # 97112	Evaluation of Speech Therapeutic Instrumental Music Performance Therapeutic Instrumental Music Performance	Musical Speech Stimulation Therapeutic exercises to develop strength, endurance and range of motion Kinesthetic sense, posture and proprioception.	$60.00

Figure 2-3: **Sample CPT codes from a music therapy session with an individual with autism.**

Unfortunately, the nature of music therapy work with the autistic population is underserved by current research reviews. The Cochrane collaboration is an international not-for-profit group which publishes quarterly up-to-date reviews regarding the effects of various health-care practices as evidenced by current research. In January of 2006, their previous review of music therapy for autistic spectrum disorder was amended [Gold et al., 2006]. Inclusion criteria were randomised controlled trials or controlled clinical trials comparing music therapy or music therapy added to standard care to "placebo" therapy, no treatment of standard care. This is a reasonable inclusion criteria, despite the difficulty in determining an acceptable standard for "placebo" therapy. Regardless of this issue, the authors were only able to include three small studies (n=24). The music therapy interventions were short-term, with daily sessions only over one week. Although music therapy was found to be superior over "placebo" therapy for verbal and gestural communicative skills, there was no significant effect over behavioral measures. Primarily as a result of the lack of appropriate sample size and longitudinal study, the current research in music therapy for autistic spectrum disorders is of insufficient methodological quality to have applicability to clinical practice.

2.3 Cognitive Training

Human development consists of a balance between genetic predisposition and the constant reshaping of the brain by the environment and learning. The later process is the playground of neural plasticity. Recent advances in neuroscience have identified the maleability of cells across the brain, as they adapt to the repetitive input stimuli of the environment and contexts under which we live and act.

Now is an era where a popular understanding of cognition and perception is unprecedented. Journalistic opportunities abound where the goal is to convey to the general population advances in scientific disciplines such as neural plasticity. The concept of a malleable, plastic, human brain is not necessarily new. Plato writes of the mind in an exploration of judgement. His Socrates asks the student to consider the mind as a wax block, upon which our perceptions are imprinted as memories. Plato then entertains the idea that this process is imperfect as we struggle to compare and reference our imprints to reality of experience. Philosophy aside, in daily life, the transition of the child from newborn to a thinking, feeling agent that acts independently in this world certainly needs no scientific explanation to convince the public of the plasticity of human development. Scientific advances in the dynamic, flexibility of the brain fit well with the impermanence of the human condition, and the popular observation of impermanence in everyday life.

Unfortunately, the topic of cognitive training is problematic because of the different emphasis it receives in popular and scientific literature. One nuance often lost in the literature is that findings in neural plasticity, cognition, and the ability to alter cognitive functioning over time, are are not integrated with one another by default. In an attempt to describe cellular-level findings and their farthest reaching tentative implications, neural plasticity and the systems level of cognition are frequently misconstrued. The study of cognition takes place on a systems level. Memory, vision, motor performance, executive function, and other cognitive domains are seated in structurally and functionally different areas of the brain. Cognition researchers seek to understand the contexts in which different areas of the brain are necessary or sufficient to execute behavior. In neural plasticity researchers are concerned with cellular level findings. Plasticity researchers investigate how nerve cells communicate with one another, how that communication changes over time, how those cells are distributed across the brain, how they develop, and finally, how these processes change with disease. Both areas of research further the understanding of the mind and behavior. However, the granularity in which cognitive and neuroscientists independently investigate the antecedents of mind and behavior requires careful navigation to determine how findings of different scope can be informative for cognitive training.

Another nuance frequently overlooked is the difference between cognitive training for a particular task and cognitive training that is potentially useful for larger sets of generalizable skills to various social and behavioral contexts. Despite recent efforts to design applications that propose to train your brain, it is unclear whether or not task specific training transfers in any significant way to domains other than those immediately trained [Baltes et al., 1989, Dick et al., 2000, Palmeri, 1997]. Of particular interest are studies training speed of processing in elderly populations[Wood et al., 2005]. Of all the cognitive function domains, one would think that speed of processing would transfer to generalizable benefit, but the supportive research is unclear at best. Speed of processing learning, and the neural plasticity surrounding the response, has been shown to have drastically different results depending on the domain in which you are training for speed [Fahle, 2005].

The following example navigates the transfer of function dilemma defensively and clearly. Ball and colleagues evaluated three cognitive training interventions over a two-year period with a 2832 person sample of individuals aged between 65 to 94 [Ball et al., 2002]. Subjects were randomly assigned to groups training for memory, verbal function and speed of processing. Each intervention was shown to improve the targeted cognitive functioning within the trained group (speed of processing, 87%, reasoning, 74%, memory, 26%; $P<.001$). Furthermore, training effects were of a magnitude equal to the amount of decline expected over the two years of study. However, training effects were not found to transfer to everyday functioning.

In one example from auditory training, Temperley and colleagues were able to show transfer of learning from the labial stop sound trained on to a novel alveolar stop presented after training[Tremblay et al., 1997]. They offer mismatch negativity cortical evoked response analysis as evidence for the perceptual transfer. This study does not demonstrate learning in a clinical population. Rather, it demonstrates the potential for generalizable perceptual plasticity between a trained and novel stimulus in an auditory training paradigm.

Cognitive training should not be confused with cognitive-behavioral therapy, which is sometimes referred to as cognitive therapy. Cognitive-behavioral therapy is a psychosocial treatment philosophy that attributes maladaptive behavior to faulty cognitive patterns. Treatment under cognitive-behavioral therapy typically involves working with a patient to identify the assumptions and thoughts that contribute to their way of acting in the world. Then, traditional behavioral techniques are developed to assist a patient in restructuring their assumptions and patterns of acting. Whereas cognitive-behavioral therapy uses cognition as synonymous with ”patterns of thinking”, the cognitive training pertinent to our investigation identifies specific domains of cognition, such as memory, motor learning, visual-spatial processing, speed of processing, etc., and seeks to modify performance in those domains through training. Cognitive-behavioral therapy lacks any specificity as to domain-specific cognition.

Furthermore, cognitive training is different from education. A useful analogy exists in the field of human computer interaction (HCI). The field of HCI is driven by goal-oriented design. Computing platforms tend to be inordinately complex. To combat the inclusion of features that add functionality but distract from the ease of use, interaction designers frequently call for applications to be designed around a user's goals. Goal-oriented design distinguishes between goals and tasks. A goal is the result that a user is trying to accomplish. Considering education, to quote Piaget, “the principle goal of education is to create men who are capable of doing new things, not simply repeating what other generations have done - men who are creative, inventive and discoverers.” Tasks are the steps implemented to achieve a goal. In education, this is some kind of a learning environment and the tools implemented in that environment.

A cognitive training application has a goal that differs from that of education; namely, to support the development of strategies to improve performance in one or several specific cognitive domains. Cognitive training, both in and outside of the clinical context, is distinguished by an adherence to domain specificity. It requires the direct targeting of mechanisms in areas such as memory, motor function, executive function, visual-spatial function, and other functional domains.

Although general education can modify performance in specific cognitive domains, it is not designed with that single goal as a directive. Education is not optimized to change cognitive function, nor does it have the assessment mechanisms built into it whereby domain specific cognitive changes could be evaluated. For healthy populations in addition to populations with a cognitive profile exhibiting deficits in core areas, to drive cognitive change in a consistent, structured, and purposeful manner, applications must be introduced that target domain specificity as a goal.

A diverse set of cognitive training applications are currently available for pathological and non-pathological populations. There is no consistent definition of cognitive training. As a result, many applications suuch as neurofeedback, auditory and other perceptual systems training, memory training, speed-of-processing training, training learning and memory strategies, various rehabilitation techniques for traumatic brain injury, schizophrenia and Alzheimer's disease, all claim to be cognitive training or rehabilitation. A lack of definition does not hinder the research community. In the better examples of cognitive training, when describing their methodology and outcomes, research scientists often avoid terms like training and rehabilitation altogether. In lieu of such cumbersome and potentially naive terminology, researchers typically present findings relevant to the pathology and areas of cognitive function in question as simply as possible. However, research continues to dissolve into the public sphere as "cognitive training". The need for a definition of cognitive training only grows as commercial software becomes available that propose to rely on scientific evidence to provide cognitive training. A definitive common ground can be established, allowing applications to be evaluated on their scientific merits and adherence to common practices.

Cognitive rehabilitation has benefitted from efforts by government supported neuropsychological organizations, in an attempt to develop standards of treatment particularly with traumatic brain injured patients. Historically, traumatic brain injured patients are treated with a multi-modal program to affect areas of cognitive deficit in addition to areas of motor deficit. This can include rehabilitation for memory, attention, judgement, self-awareness, and other cognitive domains. In 1992, the Brain Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine provided a definition of cognitive rehabilitation. Cognitive rehabilitation was defined as a "systematic, functionally-oriented service of therapeutic cognitive activities, based on an assessment and understanding of the person's brain-behaviro deficits." The group further differentiated between two branches of treatment to accomplish this end: by "(1) reinforcing, strengthening, or reestablishing previously learned patterns of behavior, or (2) establishing new patterns of cognitive activity or compensatory mechanisms for impaired neurological systems[Harley et al., 1992]."

In 1998, the National Institute of Health published a consensus statement on Rehabilitation of Persons with Traumatic Brain Injury in which a non-advocate 16 member panel from various medical disciplines recommended that rehabilitation services should be matched to the needs, strengths, and capacities of each person with TBI and modified as those needs change over time; and rehabilitation of persons with TBI should include cognitive and behavioral assessment and intervention[National Institute of Health, 1998].

The definition of cognitive rehabilitation was in direct response to treatment practices for traumatic brain injury that became standardized across the field of clinical neuropsychology. Cognitive training has no such effort underway due to the lack of population specificity and a lack of treatment context. Regarding population specificity, in cognitive rehabilitation for traumatic brain injury, the same standards can be applied to treat cognitive deficits that are similar across very different diseases, such as Parkinson's and traumatic brain injury. In cognitive training, it is unlikely that the same standards could apply to improve memory for different age groups. Defining cognitive training suffers from a scope that is often too broad. Regarding treatment context, deficits in cognitive function give an unambiguous set of abilities for which improvements or compensation are implied. When extended to the functionally normal demographic, the value of improvement does not have the baseline necessary to warrant a comparison of post-training performance to prescribed intervention.

Autism is the ideal medium between cognitive training and cognitive rehabilitation with which to explore these methodological issues. An individual with autism displays cognitive features that are atypical. We can target these features within our task design. However, the role of these cognitive features in relation to the primary behavioral deficits of an individual with autism is unclear. The opportunity exists to systematically work with describable and measurable functional abilities while examining the correlation between changes in those abilities and larger behavioral issues. In doing so, the methodological results will be relevant to cognitive training in being able to propose an application design where functional regions of interest may inform larger behavioral contexts. If this proves possible, then cognitive training for the general population may be able to target functional abilities and link improvement to aspects of behavioral function. A definition of cognitive training based on application design techniques would then be appropriate.

There are extent issues facing the viability of cognitive training as a field. The establishment of application design principles will help lead to a viable definition of the standards and practices for cognitive training across patient populations, target pathologies, and for the general population. As a result, rather than designing an application in the wake of vague scientific rationale, and hypothetical improvements that do not necessarily transfer to useful domains of everyday function, applications like the one described in this thesis will be able to be evaluated against one another to determine the most cost effective, and clinically salient implementation of new interfaces.

2.4 Summary

This literature addresses three different fields that have potential to be integrated by novel technology design - autism research, music therapy and cognitive training. In the autism review, perspectives are offered on a select few of the biological topic areas that have emerged over the past few years. From myelination processes, to cerebellar abnormalities and mirror neuron systems, it is important to recognize that this work is in its infancy. Autism is not likely to be exclusively caused by any of these systems. Rather, the interesting question is to what degree these areas are necessary compared to sufficient to describe the complex range of social and communicative symptoms that are unique to the disease.

Music therapy is a field that has a trajectory towards neurobiology and evidence based measures of treatment efficacy. An interaction is taking place between therapists and scientists. Science is embracing music as a unique mechanism of input into diverse neurological systems. Therapists are turning to science to find the mechanisms that drive the improved performance that they see as part of their treatments. It is possible to design a therapeutic interaction from recent advances into cognitive features of the disease; Although, in the future, a suitable neurobiological framework for structuring a novel intervention may present itself.

In examining cognitive training research we entertain the prognosis of a novel treatment meant to target areas of cognitive deficit. Despite targeting cognitive domains that are dysfunctional in the autistic population, it may be a false step to try and fit our applications to the term cognitive training. It is possible that an application, through repeated use, may alter performance in the cognitive domains emphasized within the application. However, training is more than differential performance over time. Transference of improvement to tasks other than those trained on, yet that target similar cognitive domains, is essential to claim that the application has cognitive training effect. The studies to prove transfer are longitudinal in nature, and difficult to conduct due to time, suitability of alternative tasks to those trained on, and the selection of an appropriate control. First, our applications will need to show performance differences over time in the trained task, and perhaps correlation to social variables. Then, rigorous methodology can be put into place to elevate the application to cognitive training status. The field can benefit from publication of the entirety of this process.

CHAPTER THREE

Initial Work

3.1 The Hyperinstruments Group

New music controllers and interfaces are designed to extend the creative potential of artists. At the MIT Media Lab, the Hyperinstruments research group, led by Tod Machover, has focused on this area of application design since 1986. Initially, Machover and his students developed applications for professionals. For example, the Hypercello was built for Yo-Yo Ma. It is a highly specialized sensor system that generates data related to the nuance of physical movement around the instrument. This data is then input into a computer system, where it is analyzed and fed back into the performance space as sound events. The system effectively allowed Ma to interject computerized sound that correlated to his physical movement into the performance space[Machover, 1992, Machover, 2003].

In the mid-ninetees, the Hyperinstruments group became interested in extending creative potential for non-experts. The Brain Opera was a touring multimedia music arcade, where the audience was free to explore various interactive music interfaces before participating in a performance that combined their created material with that of trained performers on novel electronic instruments[Paradiso, 1999].

After the Brain Opera came the Toy Symphony project. Toy Symphony generated a suite of applications that allowed children with little to no musical background to compose and perform music with the world's leading professional orchestras. The structure of the Toy Symphony project consisted of a period between several weeks, to several months, where the designers of the various Toy Symphony technologies would run workshops with the children on new music technologies[Jennings, 2003].

The workshops allowed children to participate in rhythm turn-taking games on networked rhythm performance controllers, requiring awareness of the contribution of different group members, and improvisation skills. With music shapers, a set of squeezable sound manipulation instruments, children learned how to distinguish, alter and categorize complex sound timbres as part contributing their own sounds to orchestral performances. Also, with the Hyperscore composition environment, children created their own short orchestral compositions, with little to no prior music experience necessary

The culmination of the multi-session workshop was an event hosted by a major symphony orchestra featuring the child performers and composers. Pieces written in the Hyperscore environment would be transcribed and played by the orchestra. Tod Machover's compositions were also performed by the symphony, with the children as guest soloists on their Beatbug and Music Shaper interfaces. Toy Symphony performances took place in various international venues, from Boston, to Dublin, Berlin, New York and Glasgow.

The Toy Symphony project demonstrated the power of well-designed music interfaces to allow populations other than professionals to experience aesthetically valid composition and music performance. Tod Machover, in a review of toy symphony technologies, stated, "The Music Toys proved to be engaging and easy-to-use, allowing for maximum musical expression without many of the technical and educational difficulties associated with traditional music learning experiences." [Machover, 2004]

Of the Toy Symphony projects, the technology that most directly relates to interface design for clinical populations is Hyperscore [Harmoy Line Music, 2006].

3.1.1 The Hyperscore Application

The Hyperscore application provides a composition experience that is very different from traditional composing. Rather than working through music notation, rules of orchestration and harmony, Hyperscore allows the composer to draw musical material as a series of lines and curves. Lines serve as abstractions of complex harmonic and melodic concepts. By manipulating lines, the user is able to create a musical score for string orchestra, complete with well-organized harmonic content. Hyperscore's overall effectiveness as a tool for composition novices lies in its ease of use, and a balance between what the system does to organize your musical material and what parameters of creative control are left solely to the composer.

To compose in Hyperscore, the user first creates melodic material in a "motive window". Pitch is assigned to the y-axis. Time is assigned to the x-axis. User's place notes on these axes, giving shape to a melody. Melodies can be of variable length, as the "motive window" can be resized to accomodate melodies of different duration. A user also has control over note volume and tempo. Lastly, all melodies are identified by their color. To compose multiple motives, a user specifies different colors for different motives. After having composed a melody, the user is ready to paint a composition in the "sketch window." Both the melody and sketch window can be seen in 3-1.

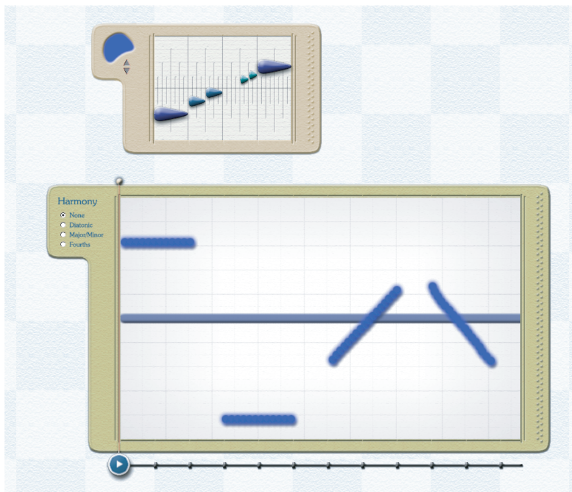

Figure 3-1: **Hyperscore motive and sketch windows, taken with permission from [Farbood, 2006]**

In the second step of the Hyperscore composition process, a user selects the color of a motive to enter into the score. By drawing a line in the sketch window, the motive gets placed in the score at the start of the line, and will loop continuously for the duration of the line. The sketch window also has pitch and time axes as in the motive window. If the line changes on the y-axis, the melody gets remapped to fit the contour of the line. As an example, the motive in 3-1 gets remapped by the accompanying sketch window. The musical result is notated in 3-2

Figure 3-2: **Translation of the melody in 3-1 through the given sketch window, taken from [Farbood, 2006]**

If the composer were to use these features to place melodies into the sketch-window with no consideration of their harmonic relationships to one another, the result would be a cacophonous piece lacking in harmonic organization. The most useful feature of Hyperscore is that it circumvents this issue with the harmony line. The composer is able to select from three available harmonic systems which organize the disparate motives so that the notes fall within a centrally unifying tonality, or key. By manipulating the curve of the harmony line, situated at the center of the sketch window, a composer creates harmonic changes over time. The result is a harmonically rich piece, which remains true to the composers intentions while offering a modicum of assistance.

3.1.2 Hyperscore at Tewksbury State Hospital

Initial work in the area of composition interfaces for clinical populations took place at the end of the Toy Symphony Project. The Massachusetts Council for the Arts, Vermont Arts Exchange, Berklee College of Music and Tewksbury State Hospital, in tandem with the Tewksbury 150th Anniversary, contacted Tod Machover in the wake of the Toy Symphony project to consider whether any of the Toy Symphony tools could be useful for clinical populations. Between January and May 2004, the Hyperscore program was brought to Tewksbury as a pilot test to evaluate the appropriateness of novel composition tools for diverse clinical populations.

Tewksbury State Hospital is a 540 bed residential hospital offering programs in Huntington's Disease, acute and chronic care for adults and geriatric adults, psychiatric services, and substance abuse. The hospital campus is divided into two different wings, offering some isolation between the physical health and mental health departments.

Weekly one-hour sessions were comprised of two groups. The first group was from the psychiatric wing and contained approximately nine subjects. Subjects were selected by hospital staff. Diagnoses included moderate schizophrenia, depression, and bipolar disorder. Hyperscore sessions were conducted with patients receiving assistance from two student music therapists, and an MIT undergraduate with musical training. The psychiatric unit nurse practitioner was also present for all sessions, but did not engage patients directly.

The second group consisted of approximately thirteen patients from the physical health department. Subject diagnoses were as diverse as spina bifida, Alzheimer's Disease, cerebral palsy, congenital blindness, and Huntington's disease. Due to the motor control symptoms of many of the patients, the second group received much more support from hospital staff and one another. Four of the patients were paired at computers in two person groups. Pairs were constructed such that one patient's motor abilities would complement another's. Other than the pairs, patients in the physical health group received a lot of one-on-one support from hospital staff. Staff assistance in both groups was relatively stable across sessions. Staff paired with patients early in the project, allowing for relationship and rapport building around the composing tool. The hospital staff from the physical health group consisted of two student music therapists, staff occupational therapists, an expressive arts therapist trained primarily in drama therapy, a professional music therapist, Tod Machover, and nursing staff..

In the initial sessions, the format included a familiarization block that lasted about ten to fifteen minutes where the researcher would present a new feature of the Hyperscore program and answer any questions. This was incrementally taken out of the session structure because patients expressed competence with the software by the third and forth week, and seemed to prefer the additional time to work on their compositions. Staff was always available to answer questions regarding the interface.

The session work at Tewksbury Hospital was a unique opportunity that provided a novel platform for communication on a level previously not available due to the disabilities exhibited by the patient population. In some ways, an inability to communicate can be considered as part of the primary diagnosis for each patient that we were able to work with. On the mental health unit, the patients were debilitated as part of isolating factors of their mental illnesses. On the physical health unit, there is a clear line drawn as to the level of communications that are implied for a patient with little or no control of muscle movement in their bodies, save for eye and tongue control as was the case for one patient whom we worked with. In general, the patients have communicative and expressive needs that are ameliorated by more than the simple presence of therapists or mentors utilizing music as a tool. Adaptive and creative technologies are quite literally providing the opportunity for patients to have a voice.

3.1.3 Differences Between Hyperscore and a Clinical Tool

Several assessment measures have been designed to substantiate the effectiveness of Hyperscore in the hospital setting. An example qualitative measure is a simple behavioral pre- and post-assessment meant to document general observations, such as engagement, instruction following, group communication, mentor/therapist communication and other, and measures specific to a particular patient's diagnosis. The assessment utilizes numeric ratings, between 1 and 5, and is ideally made by a third, independent party as outlined in Appendix A.

Beginning to consider Hyperscore in terms of its clinical utility raises a series of issues, in part, because Hyperscore was not designed to address patient needs. Firstly, the qualitative and behavioral measures one would apply to interventions with Hyperscore do not tend to parse out effect due to placebo treatment. Also, it is unclear whether or not the Hyperscore tool is better than other complementary tools available for ameliorating symptoms of disease, psychosocial or otherwise. The underlying question is, can the work at Tewksbury be considered a therapeutic treatment? Consequently, what protocol needs to be introduced to evaluate the efficacy of novel clinical tools? These questions fall under the jurisdiction of the burgeoning field of bioethics for complementary alternative medicine(CAM).

In the Spring of 2006, The National Institute of Health(NIH) adopted its first fellow in CAM bioethics. Between its establishment in 1998 and 2003, the National Center for Complementary and Alternative Medicine, an institute of the NIH, increased its budget from $ 50 million to $ 122 million dollars[Straus and Beldon, 2006]. This followed in response to the growth of CAM use by the American public. One-third of adults use some form of CAM[Barnes et al., 2002, Eisenberg et al., 1993]. Music and arts therapies are by not the most frequently used complementary therapies, especially when survey data includes health directed prayer, homeopathy, massage, and yoga. People tend to turn to CAM because they find the alternatives consistent with their values and philosophical orientations[Astin, 1998]. Support for CAM is prevalent in traditional medical practice. A 1994 survey of physicians from various specialties in the United States and Isreal found that 60% had recommended alternative therapies in the preceding year[Borkan et al., 1994].

Evidence-based validation of novel therapies, whether they are based on technological developments(such as Hyperscore), alternative therapeutic practices (such as music therapy), or a combination of both(the Tewksbury project), require the same systematic evaluation standards as traditional treatments. The Institute of Medicine of the National Academies recently published a volume where:

> "the committee recommends that the same principles and standards of evidence of treatment effectiveness apply to all treatments. whether currently labeled as conventional medicine or CAM. Implementing this recommendation requires that investigators use and develop as necessary common methods, measures, and standards for the generation and interpretation of evidence necessary for making decisions about the use of CAM and conventional therapies". [Institute of Medicine, 2005]

The implied experimental standard is randomized controlled trials. The basic premises of randomized controlled trials are the random assignment of patients to experimental and control groups, keeping patients blind as to which group they are in, and the experimentors blind as to which group the patients are in. Overall, the methodological goal is to account for bias regarding subject selection, expectation of results, placebo controls, and other factors. This methodology is especially useful for pharmacological research. Where therapies are being evaluated, the holistic nature of a therapy may intrinsically bias a patient to realize that they are receiving novel treatment. Alternative methodologies have been proposed to deal with this issue while preserving the goals of randomized controlled trials. Although, even in circumstances where rigorous adherence to randomized controlled trials may distort the traditional treatment context for a given CAM, it is the methodology that is most likely to provide scientific validity for any novel treatment [Miller et al., 2004]

However, before randomized controlled trials can be implemented, significantly more work has to be done to develop an understanding of the scientific basis upon which plausible effect is judged and attributed. Herein lies the difficulty in CAM evaluation. The barriers to the introduction of alternative treatments into the healthcare system are not that they require a more rigorous evaluative experimental design. When considering a treatment as ill-defined as the use of music composition software to ameliorate a given symptom, the predominant barrier is the lack of biologically plausible mechanisms for why or how such a tool could be useful to combat the biological antecedents of the given symptom. In most cases, there's little to no connection between the therapeutic musical interaction and underlying biology. The need to implement randomized controlled trials is an administrative issue. Academic journals and medical reimbursement services are free to dictate the standards by which treatments are acceptable for publication or remuneration. The work that needs to be conducted for Hyperscore, and other novel musical tools so they may be applied as clinical treatments, is the attribution of the operating musical interaction to underlying biological mechanisms.

The neurobiology of music is a promising new field. Music interfaces for pathological populations need to rely on the findings from this field in every aspect of their design. In doing so, applications can be discussed on a level that is more scientifically substantial than simply being able to extend creative opportunities and quality of life for patients. Hyperscore is an example of an application that is remarkable in its ability to allow anybody to compose music, irrespective of previous musical literacy. It is a program that has been shown to improve quality of life and provide creative opportunities for patients with a wide array of functional and mental pathology. However, it was not designed to target domains of symptomatic dysfunction for any population. As a result, their is no basis to evaluate how it compares to other tools or treatments. Furthermore, there is no basis to posit an underlying cognitive or neurobiological antecedent of the observed effect of Hyperscore in the clinical setting.

The difference between Hyperscore and a clinical tool is specificity. Without targeting specific domains of cognitive or neurobiological dysfunction a new music interface will suffer from clinical applicability relegated to, at best, increasing quality of life and socializing behaviors. A lack of targeted symptoms equates to a lack of goal direction, and an inability to assess outcomes.

One area that does not suffer is accessibility through a lack of clinical specificity. At any point in the integration of a novel tool to a clinical setting the interface can be adapted to meet the functional needs of a patient. As an example, at Tewksbury hospital a quadriplegic patient suffering from cerebral palsy was outfitted with an infrared sensor that interfaced with an application to control the mouse on the PC running the Hyperscore application. This allowed the patient to paint motives and create compositions by moving his head. The creative accessibility of the application was not modified. Provision of a physical interface is an engineering issue that is not a critical barrier to the integration of novel technologies into clinical practice.

3.2 Paired Associates Learning and AD

3.2.1 Rationale

The first application to explore concepts of embedding quantifiable neuropsychological measures into composing applications targeted Alzheimer's patients. The task was meant to be used as an assessment measure for early onset detection of mild cognitive impairment and Alzheimer's disease. It is now understood that the Alzheimer's disease primarily targets cholinergic neurons in a cascade of molecular events that can be targeted by various pharmacological treatments. The future of Alzheimer's treatment lies in pharmacology to ameliorate symptoms or alter the time course of the disease through neurobiological means. In tandem with treatment research, the field of early onset detection of Alzheimer's disease holds promise for several reasons. Onset detection applications are implied to maintain the highest level of functioning possible for the longest period of time and to establish protective measures at the earliest signs of disease[Swainson et al., 2001, Nestor et al., 2004].

The cognitive domain in question is visualspatial associative memory as measured by paired associates tasks. Our paired associates task takes a user generated audio sample, and pairs it with a three dimensional abstract visual image. After a short delay, the subject must recall, with an auditory cue, which of four images was the one paired with with the audio cue. Paired associates tasks are implied for early onset detection because the areas of hippocampus and perirhinal cortex that are the earliest sites of neurodegenerative symptoms related to Alzheimer's disease[Lee et al., 2006, Teipel et al., 2006, Van Hoesen et al., 2000] and have been shown to be activated during associative encoding tasks[Pihlajamäki et al., 2003].

The paired associates task has working memory and executive function components. Working memory is the active and temporary representation of information that is maintained across short delays to control behavior[Gluck et al., 2006]. Closely related to working memory is executive function, which is the ability to operate on working memory to succeed in tasks such as goal formation, planning, joint attention, and task switching. Measures of delayed recall and executive function have been shown to be the most sensitive neuropsychological tests to distinguish between those who are presymptomatic and would eventually transfer to Alzheimer's disease[Chen et al., 2000].

3.2.2 Design

The interface goal was to provide a controller that would be more easily integrated into homes within the elderly community. To meet this goal the entire functionality of the composing application is accessible by using two continuous variables, on an x-y cartesian plane, and four buttons. The cartesian plane allows a user to make continuous parameter changes as they select and move through the plane. At first, this control paradigm was built into a glove interface, designed by David Sachs [Sachs, 2005]. Then, for development purposes, the control paradigm was implemented in software as shown in Figure 3-3. The black box is the plane where a user moves the mouse to make continuous selection.

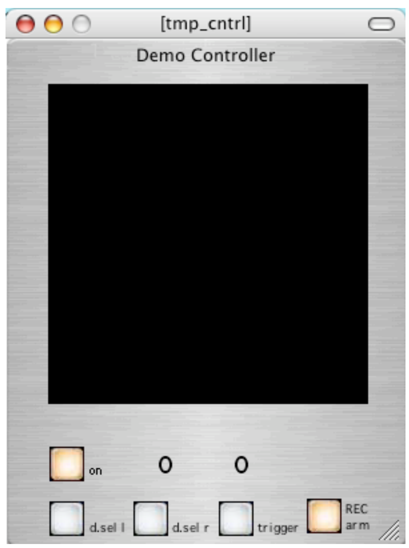

Figure 3-3: **Software implementation of controller for Paired Associates software. The black square is a cartesian plane allowing users to click and drag the mouse in two dimensions, which is mapped to two parameter values.**

The application has two parts, a sound editor and neuropsychological test. In the sound editor, users progress through a series of steps. At each step, the user gains access to two sound variables that they get to alter by moving the mouse in the cartesian plane. At any given point in the plane, the x and y variables get mapped to two parameter variables of the selected instrument. When the desired sound of the instrument is achieved by modifying the instrument's parameters, the user can save the sound into a library of collected sounds. This method of sound design is particularly conducive to altering complex sounds. By forcing incremental changes in a small sets of variables, the user is able to explore how many different parameter values can independently contribute to the resulting timbre. Also, differently from a midi notation or piano roll implementation, when traversing a tree of incremental parameter changes the user is biased to consider the sound they are creating rather than the pitch contour, phrase, or melodic unit that is often the primary concern of traditional methods of composition.

While users are making incremental alterations to sound timbre, parameters of a three dimensional graphic are also being altered by the changes in sound. The three dimensional graphical part of the application is where we build our neuropsychological task. Visual parameters include, color, light source position (which determines shading), curve control point position, and object position in 3d space. Visual parameters are arbitrarily assigned to sound parameters. For instance, changing the brightness of the timbre does not change the brightness of the visual object. The result of this visual and auditory generative process is the creation of a complex, abstract auditory and visual pair. Example visual stimuli are shown in Figure 3-4.

Figure 3-4: **Visual stimuli created simultaneously while editing sound.**

Having generated audio and visual pairs, the user then selects to use the audio in their sequencer. The sequencer allows the user to layer the sounds they have created into a composition. A detailed description of the sequencer application is outside of the scope of this review.

After having created the auditory and visual pair, and before the user is able to access the sequencer layer of the application, the user takes a neuropsychological test of their working memory. The user is simultaneously presented four visual images, one of which is the image that he or she created. The user then hears the timbre that they created as a cue. The user's task is to choose the visual image that was paired with the auditory cue. To defeat the potential for a user to encode a single parameter of the target visual as a strategy to detect the target in the test, distractor images are generated so that a randomly chosen variable of the target visual is invariant across distractors. Some distractors are also generated as reversals of either the correct target or other distractors.

If the user gets the first paired associate question correct, the next trial will test on the last two previously created pairs. Subject performance is measured by the number of pairs that they can remember.

The core development environment of the paired associates application is Max/MSP and Jitter. Digital audio manipulation utilizes cSound. (refer to chapter 4).

3.2.3 Research Questions Raised

This application was never introduced into the clinical setting due to critical flaws in its design. However, it did raise several interesting questions that are being pursued as part of a multi-institution research effort examining embedded cognitive assessments into novel applications for at-risk elderly.

Firstly, how does auditory-visual working memory compare to the traditional visual-spatial working memory tasks that are typically employed for the assessment of cognitive decline in elderly populations? An auditory-visual task may make completely different cognitive demands then a purely visual-spatial task. For the population of geriatric patients with Alzheimer's disease, memory for music is often anecdotally cited as being maintained [Cowles et al., 2003, Crystal et al., 1989, Cuddy and Duffin, 2005] while visual-spatial and episodic abilities decline in the earliest stages of the disease[Perry and Hodges, 1999, Geldmacher, 2003, Bäckman et al., 2004]. Will the auditory-visual spatial task require a similar cognitive load to the purely visual-spatial task? In general, a novel clinical application that proposes to operate on a cognitive domain, but bases its task design on literature from a different domain, requires an evaluation as to the extent that the task transfers between the two domains.

Secondly, how does the subject's vested interest in the stimuli of the neuropsychological component effect the outcome of task? Relatively little work has been done to create neuropsychological tests in which subjects generate their own stimuli. Petrides' self-ordered working memory tasks begin to examine questions of subject choice[Petrides, 1995, Petrides et al., 1993]. However, in Petrides' tasks the user does not have a role in the creation of the stimuli they are going to be tested on. Resolving this research question of user input into neuropsychological assessment has broad implications for the field of novel applications with connections to cognition. From cognitive training to education and treatment, if the performance of subjects could be anticipated even in circumstances where they were offered engaging control over the tools, it would not be overly ambitious to propose that you may find improved compliance and performance over the traditional situation, which relegates a subject to that of somewhat passive participation. Arguably, one of the phenomena of a musical interaction in the clinical space is that the patient is offered a semblance of control over their own treatment circumstances.

Also, how does performance on this task vary based on musical literacy? Does it change over time? The sound editor task required the user to pay careful consideration to sound changes with the goal of integrating many different sounds in layers in a composition in addition to the goal of performing well on given neuropsychological task. The interaction between these two goals is not well controlled. Potentially, musically inclined individuals will benefit from less cognitive load in the compositional goal, and will therefore be able to better perform at the neuropsychological task. The opposite could also be true. Users who perform better at the composition task due to musical literacy may do so at the detriment of all other considerations, visual-spatial and otherwise.

Lastly, the paired associates application was naive in the sense that it was not a feasible environment by which elderly could compose. It was slow and tedious. The testing component was abruptly interjected in the flow of composition. Most critically, every feature of the process relied on abstraction to the extent that the system was too far from what people expected of the music creation process.

3.3 Summary

The applications described in this thesis have emerged from the MIT Media Lab Hyperinstruments group, a context uniquely situated at the cross-roads of new music technologies for diverse populations. Our applications for individuals within the autism spectrum adhere to the same design standards outlined in projects such as Toy Symphony and Hyperscore, which increased the potential for anyone to compose and perform music.

Prior work at Tewksbury Hospital showed the success of new music interfaces in a somewhat traditional music therapy setting. Hyperscore undeniably increased the quality of life of the patients we were working with. Furthermore, the general quality of the work was not restricted by patient disease. Diverse participants with various physical and cognitive symptoms were able to acquire the technology for their own creative purposes. Also, the intervention was ancillary and somewhat independent of specific patient disease. As a result, patient effect could not be gauged, and the work could not be considered as a treatment, but rather, a social intervention.

To address these issues, a new generation of composing interfaces began with work in Alzheimer's disease. The initial prototype was unreasonably complex, with a non-intuitive composing process and cumbersome interface. However, many interesting design principles were exposed in addition to threads of research that are now being pursued in collaboration with the Alzheimer's Association and Intel.

Autism presents a unique set of considerations that must be integrated into the total design of the application. Moving forward from the foundation outlined in this prior work, we can consider a system implementation that not only addresses the flaws in previous work, but can target aspects of a disease that is by definition social, and difficult to quantify.

CHAPTER FOUR
System Design and Implementation

Edgar Varèse, a progenitor of electronic and twentieth century avant-garde composition, defined music as "organized sound." The simplicity of this definition underscores the potential for music to be acquired for diverse artistic and scientific purposes. From the smallest kernel of street noise, to Beethoven's last String Quartets, music is an artifact with a spectrum of hierarchical complexity. Its up to the scientist utilizing music for diagnostic, assessment, or cognitive purposes to determine which pieces of the spectrum are suitable for his or her applications. A system designer must superimpose appropriate structure to ensure that the richness of music experience is maintained, while the units of composition that a subject manipulates are discrete, quantifiable, and well-controlled.

In outlining the implementation of new music technologies for autistic populations, this chapter will first present the cognitive domains targeted by our music tasks. Then, the focus will shift to presenting the tasks themselves, and the user interaction implied by the design choices. Lastly, details regarding the technical implementation will be presented.

The musical goal of the proposed application is to provide a creative auditory experience for an individual with autism. If the only clinical objective were to create behavioral treatment around creative experience, the introduction of a talented musical facilitator or therapist would be all that is necessary to structure the application of music created to fit joint attention sharing processes, social cueing, social timing, perspective formation, or other behavioral concerns of the intended population. In many ways, this is the standard model by which drama therapists, music therapists, and educators working with children with autism develop materials for their subject population. In contrast, the scientific opportunity is to use the creative auditory experience as a platform to target cognitive domains of interest. New music technologies are capable of buttressing the ongoing education and treatment efforts of practitioners by using creative music experiences to gather information related to cognitive domains of interest. Two applications have been designed to examine differences in processing of local versus global information, as evidenced by central coherence tasks. This cognition data, if coupled to the implementation of a behavioral treatment paradigm, has the potential to generate evidence based measures for the analysis of treatment efficacy, cost-effectiveness, plasticity of sensitive cognitive processes for a pathological population, and correlation between cognitive change and behavioral change.

4.1 Melodic Contour Task

The melodic contour task allows a user to create melodies. Over time, the user is able to generate a library of material that they can use in a variety of treatment contexts. In addition to the creation of melodies for musical and artistic purposes, users will also be challenged to perform delayed matching to sample tasks for the melodies they create. The term Melodic Contour refers to stimuli used for the delayed matching condition, where the contour, or shape of a user's melody is used to generate the visual stimuli for the delayed matching to sample task.

4.1.1 Interface and Interaction

There are three different windows of interest in the Melodic Contour environment. The first window is used to specify features of a single note that the user will be entering into the melody they wish to create. The complete set of features available for selection are note duration, instrument, timbre, and loudness. All of the feature selections, with the exception of the timbre feature, are discrete buttons used to select from a set small number of different feature values. For instance, the loudness feature has three different buttons, corresponding to "soft", "medium" and "loud", with representative graphics on the buttons. Selecting any of these features defers to the designer's decision as to what are appropriate levels to associate with the constrained number of possible feature selections. Buttons are available for note duration, represented by different relative lengths of line.

All feature selection is conducted in a separate window to encourage individuals to spend time making detailed feature selections before having the opportunity to enter in notes into the melody. The disadvantage to this design decision is that it is difficult for users to quickly try out different melodies. This can be considered a hindrance to the creative process. The advantage to this design decision is that users are encouraged to specify local feature information for the elements of the melody they are going to create. The evaluation chapter examines how users differentially utilized versions of the application that did not allow for the same amount of feature specification as in the final implementation.

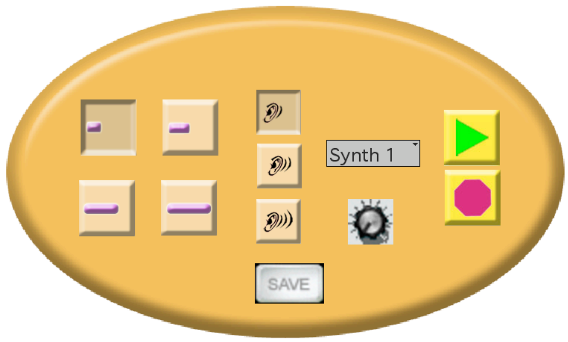

Figure 4-1: **The interface transport, for specifying features of notes to be entered into the melody window. Buttons, from left to right, change note duration, loudness, selected instrument, and control melody playback. The knob changes one timbre parameter of the selected instrument. The bottom button, marked save, writes the entered melody to the user's library of melodies, and initiates the contour task.**

There are currently three different instruments to choose from for a given note. Each instrument uses a different classical music synthesis technique to generate the resultant sound. The first instrument is a simple piano sound created from MIDI. The second is a sound created using additive synthesis techniques. The third sound is a granular synthesis sound. Together, these three options give a range of sound with drastic intrinsic differences that have implications for evaluation of user preferences, scope of material generated with the melodic contour environment, and aspects of the cognitive measure.

A single piano note intrinsically meets a user's expectations for a melodic instrument, irrespective of whether or not they have ever heard a piano before. Piano notes are discrete percussive events that are well defined both temporally and in frequency. As a result, the piano note is a well organized event in space. When delivered monophonically, with only one note being played at a time in the sequence, notes will clearly relate to one another on a variety of hierarchical levels. The piano note in the context of a sequence of notes can be cognitively processed for its local, pitch (frequency) information, its intervalic relational information between a series of neighboring local events, or for its global information in the context of a complete melodic contour or shape. Users have one variable of control over the timbre of the piano instrument. By turning a virtual knob the user controls the brightness of the instrument.

In contrast to the discrete temporal and frequency characteristics of the piano instrument, the additive synthesis instrument begins to sacrifice frequency control to create a sound that is more flexible with regard to timbre modification over time. Like the piano instrument, the additive synthesis sound is able to be executed so that it clearly delineates itself from other excitation events due to its attack characteristics, or the sharpness in which the amplitude of the sound reaches peak in the first few milliseconds after its excitation. However, the additive synthesis sound does not keep a distinct pitch frequency. Rather, it is designed to oscillate within a range of frequency for the duration of the note. The rate of oscillation is chosen so that the note sweeps over a range of frequencies, and is not perceived as a vibrato, but a slow oscillation. The median pitch is perceived as the frequency of the note, although the range of frequencies traversed by the note adds vagueness to the pitch percept. The user is able to control the range of frequency sweeping to effect the timbre of the additive synthesis instrument.

The granular synthesis instrument is the most flexible in terms of temporal and frequency characteristics. Granular sound is composed of dense clouds of sound on the order of a few milliseconds tightly packed together in time. The grains of sound can overlap one another, where their addition to one another in overlapping regions create rich harmonic timbres. Far from chaos, granular synthesis has been used for speech synthesis and is controllable despite the number of sound particles functioning in the system. For the purposes of the melodic contour generator, granular synthesis was chosen because it is a suitable method of synthesis to obfuscate the excitation of a note in time, in addition to its pitch characteristic. The timbre control for the granular synthesis sound modifies the density of the sound.

The user begins interaction with the melodic contour generator by specifying features of the note they want to place into the melody. The second step of the interaction is to place the note into a dedicated melody window. The melody window is divided into two halves to demarcate the boundary between two measures in time. The software is currently set at 120 beats per minute. The four different duration features available to a user allow temporal resolution at sixteenth, eighth, quarter and half note scale. These distinctions are built into the system and left for the user to discover. The goal is to provide a relative system for melody entry, where notes are represented as lines, note durations are simply relative to other notes and a vague central line, pitch corresponds to line height in a window, without the necessity of allusions to traditional music notation.

Figure 4-2: **Window for notating melodies in piano roll format. Y-axis corresponds to pitch. X-axis corresponds to time of note excitation and note length.**

After placing a note the user is free to place a second note with identical characteristics, or to specify features of a new note. In summary the user goes back and forth between the feature selection window and the melody placement window until their melody is complete. The final step in the creative process is to save the melody created. By hitting the save button, the user launches the delayed matching to sample task. Figure 4-3 outlines the user interaction process.

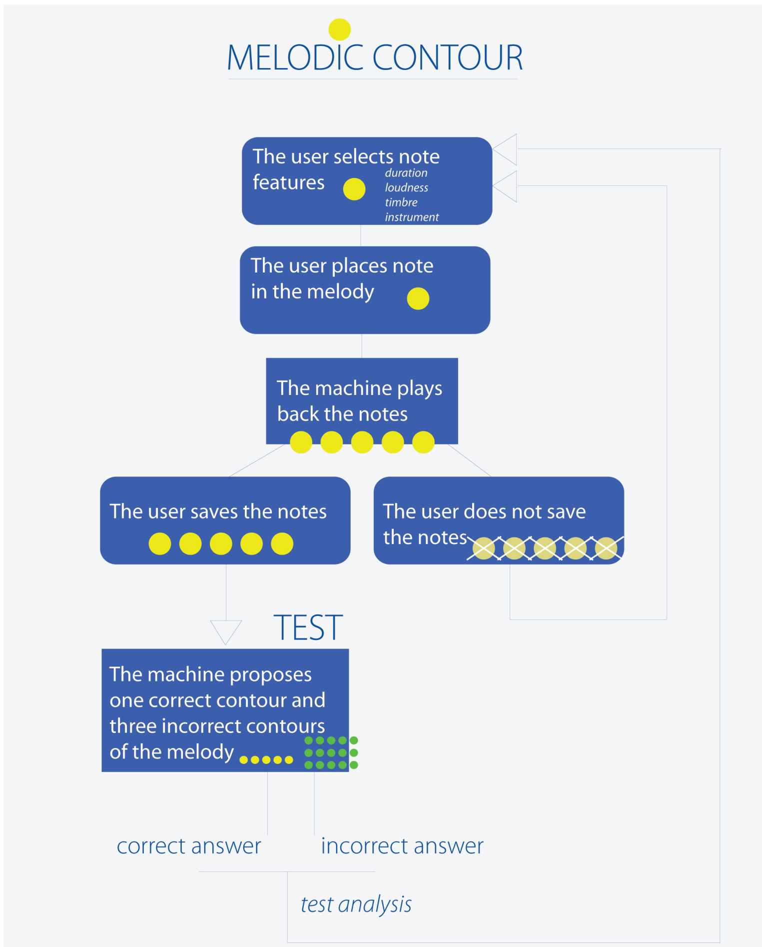

Figure 4-3: **Flow diagram depicting the user interaction with the Melodic Contour Generator.**

4.1.2 Delayed Matching to Sample

Delayed matching to sample(DMS) is a cognitive task targeting visual associative memory. Subjects must rely on working memory to encode a novel image. In the typical DMS task, after a short delay, the user is asked to select the remembered image from a series of test images. The task can be adapted to measure speed of response, retention times, working memory performance, and many other outcomes.

In the Melodic Contour task, the user's performance is measured by the ability to distinguish the melodic contour representing their recently made melody from a set of incorrect contours. Users do not receive any form of cue after having created the melody for the DMS task. In the time between creation of the melody and the presentation of testing stimuli the user must hold a representation of the melody they created in memory, and compare that representation to the abstracted melodic contours presented in the test. This approach diverges from the traditional DMS task because the visual stimuli used for the test are not the same type as the originally encoded target object. Rather, the subject generates an auditory stimulus, the melody, by drawing in a two dimensional window. Then, interjected between the encoding step and the testing step, the user must mentally manipulate the encoded melody to compare with representative visual abstractions. This modification may emphasize the working memory component of the task. One difficulty in this methodology is that the target stimulus, the melody, is created by visualspatial means. While the user arranges notes in the window where they create melodies, it is unclear to what extent the users are encoding the auditory component or the visual arrangement of notes.

To examine differences in local versus global processing the originally constructed melody needs to be abstracted in a manner that suppresses local characteristics and emphasizes the global, hierarchical structure of the original object. To satisfy this criterion, the melody is visually abstracted by an algorithm that fits a simple linear curve to pitch and time location of the different notes in the melody. The result is a simple curve that connects the notes of the melody and smoothes between different peaks caused by intervalic changes in direction. The curve is visualized in three dimensions, which is a necessary departure from the two dimensional planar representation used to initially enter the melody into the application.

The contour curve is smoothed with a moving average filter. A moving average shifts a window of n values to calculate the average for a k'th instant in the formula:

$$\bar{x}_k = \bar{x}_{k-1} + \frac{1}{n}\left[x_k - x_{k-n}\right]$$

Figure 4-4: **Formula for smoothing a curve using a moving average filter.**

The window size of n values can be set to average more values of the line to determine the filtered value of the k'th element, resulting in less pronounced peaks in the line at points where notes exist in the user's melody. For example, figure 4-5 displays a melody with three different window size constants for the value n. The evaluation chapter examines using different constants in the smoothing function and the threshold for which melodies are indistinguishable based on too much smoothing.

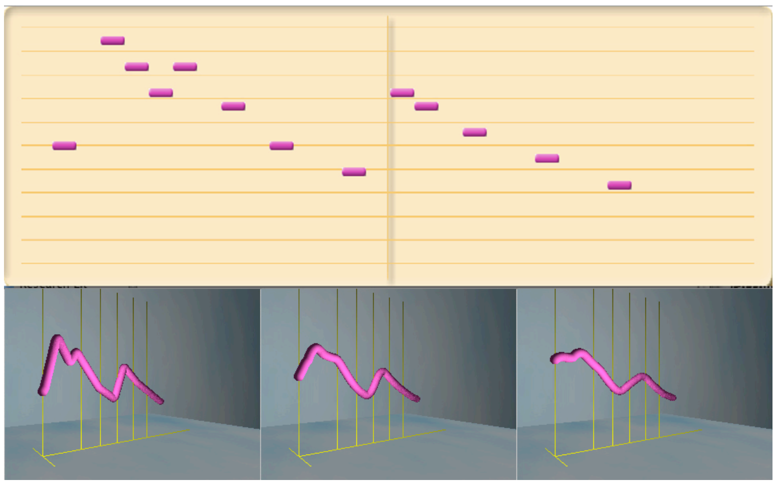

Figure 4-5: **The resultant curve after using a moving average filter with three different constants for window size n.**

The curves are generated in openGL functionality available through the Max/MSP/Jitter package. OpenGL allows the curves to be visualized in three dimensional space, with an environment defined by background graphics, lighting and shading.

Distractor curves are generated by applying one of several transfer functions to the original melodic contour. There are three different types of transfer function. The first removes a note from either the beginning, middle, or end of the melody, and recalculates a contour for presentation in the test. The second type of function removes a note as in the first, but also reverses all of the notes in the resultant contour. The last type of transfer function merely reverses all of the notes from the correct target, without removing any notes. Together, these three distractor generation methods defend against a user being able to encode only one segment of their melody, such as the beginning, and check against the samples presented in the DMS task. The target and the distractors are displayed in a random arrangement of four windows.

When a user selects an answer among the four choices in the DMS task, feedback is provided acknowledging whether the answer was correct or not. The design dilemma here is that by providing feedback the user is potentially being conditioned to the task rather than relying on their innate abilities for local and global processing in DMS tasks. However, individuals in subpopulations such as Asperger's syndrome have been known to resist changes in routine, to perseverate on stereotyped behaviors and interests. These symptoms make it plausible that devoid of any feedback, users might converge on their own arbitrary criteria for the selection of answers in the DMS task. In particular, because the DMS task does not correspond to an exact replica of a previously memorized object, but rather, requires the selection of an answer from a set of abstract lines, if devoid of feedback a user is likely to rationalize which of the abstracted shapes is representative for criteria beyond what is expected in the task.

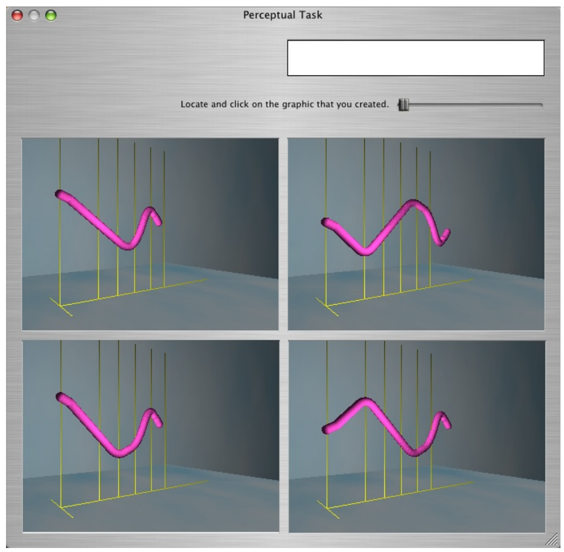

Figure 4-6: **The interface window where the DMS task takes place. One of the four lines is the correct contour for the melody input by the user in the melody window. The other three are incorrect contours. Users must select the best fitting contour for the melody they created without being able to refer back to the original piano roll notation, where the melody was entered.**

4.2 Embedded Rhythms Generator

The embedded rhythms generator allows users to create rhythms. As in the melodic contour generator, over time, the user builds a library of rhythms. Unlike the melodic contour generator, the creation of a rhythm does not have a clear utility into the composition process. Most commercial software applications allow users to assign percussive instruments to the windows where they specify melodic entry, although the emphasis is clearly on functionality for the creation of melody. The goal was to develop a novel form of rhythmic entry which could lead to different implications for integration into composing environments than what is implied for user-generated melodies. The term embedded rhythms refers to the type of neuropsychological test that the rhythm generator was modeled on. An embedded figures test is a frequently described neuropsychological measure of working memory in visual-spatial tasks.

4.2.1 Interface and Interaction

There are two different windows of interest in the embedded rhythms interface. The first window, in Figure **??**, is the instruction window. In it, the user is able to begin the rhythm recording process, receive instructions, and make selections during the testing phase. The second window, in Figure 4-11 is the visualization window. It is only used to visualize the rhythm entered by the user and is not part of testing.

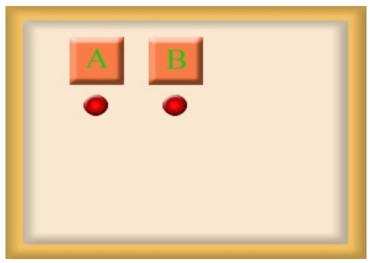

Figure 4-7: **The window where users operate the embedded rhythms application. Users are able to save the rhythms they create, respond to task questions, receive instructions, receive feedback, and reset the application to enter in a new rhythm.**

The user begins their interaction with the embedded rhythms generator by pressing start in the instruction window. In doing so, the application will inform the user that they are now able to make a rhythm, and a soft metronomic pulse will begin beating out quarter note excitations at 145 beats per minute. The user enters in a rhythm by hitting a button on the computer keyboard within the superstructure provided by the metronomic pulse. As soon as the user hits the rhythm entry button a first time, the interface begins recording. After the onset of recording the user has two measures in which they are able to specify their intended rhythm. During the recording process, hitting the rhythm entry button plays a synthetic percussion sound, providing auditory feedback to clearly define the note within the metronomic pulse. After two measures of rhythm have been entered, the interface produces the sound of a bell being struck once before beginning to loop the rhythm entered by the user.

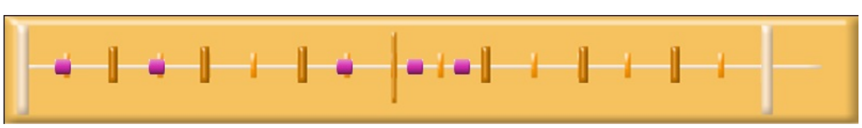

Figure 4-8: **A window for visually representing the rhythm entered by the user overlayed on a grid. The X-axis is time. The purple marks are notes entered.**

At the instant that the bell sound is activated, the rhythm entered by the user is quantized with eighth note resolution. When the looping begins, it utilizes the quantized rhythm rather than the exact rhythm specified by the user. The result is generally a "cleaner" rhythm, and tends to resolve limitations of the entry interface. The temporal sensitivity of the keyboard with which the user enters a rhythm often defeats the attempt to enter a note at a specific time. For instance, if the goal is to place a note on the fourth beat of a rhythm while the keyboard is measuring at millisecond latencies, it will be nearly impossible for the user to accurately strike the keyboard within the few milliseconds available relative to the latency of the interface. By quantizing the input, it becomes easier for a user toi succesfully enter the rhythm they intend.

After quanitzation, the rhythm plays through a loop three consecutive times. Allowing the user the opportunity to familiarize themselves with the auditory object that they had just created before accepting to save it or not. This design choice was made due to the different perception of an auditory object in its creation compared to the active listening for an object, without the physical and cognitive criteria to execute the performance in real-time. After the rhythm has looped three times, the interface asks the user if they would like to save the rhythm. If the user selects yes, then the entered rhythm gets saved, and the embedded rhythms evaluation begins. Figure 4-9 depicts the flow of user interaction through the Embedded Rhythms application.

4.2.2 Embedded Figures Test

An embedded figures test is measure of working memory in visual spatial tasks. In an embedded figures test (EFT), the subject is typically given a complex visual image and asked whether the target simple image is present in the complex image. Performance on an EFT is typically evaluated by response time and accuracy. EFT performance is one of the areas where autistic individuals show increased performance over age and IQ matched controls for both accuracy[Shah and Frith, 1983] and response time[Jolliffe and Baron-Cohen, 1997]. Furthermore, it is generally accepted that an EFT disproportionately requires processing of local features of an object, irregardless for the complexity of the global image. It is incorporated into many experiments examining the validity of central coherence accounts of autism.

In one promising study, an embedded figures task were adapted for suitability in an fMRI experiment with six individuals diagnosed with either autism or Asperger's and 12 control subjects matched for age, IQ, socioeconomic background, and handedness[Ring et al., 1999]. Although there was no significant difference in task performance between the two groups, the control group exhibited greater activation in prefrontal cortical areas, compared to the autistic group which exhibited greater activation in occipital cortex and temporal gyrus. The authors contend that between group activation differences supports reliance on different cognitive strategies. For the control group, activation is seen in areas involved in higher order working memory and visual perception, while the autistic subjects utilize areas related to primary and association visual processing. There are methodological issues with this study, including a

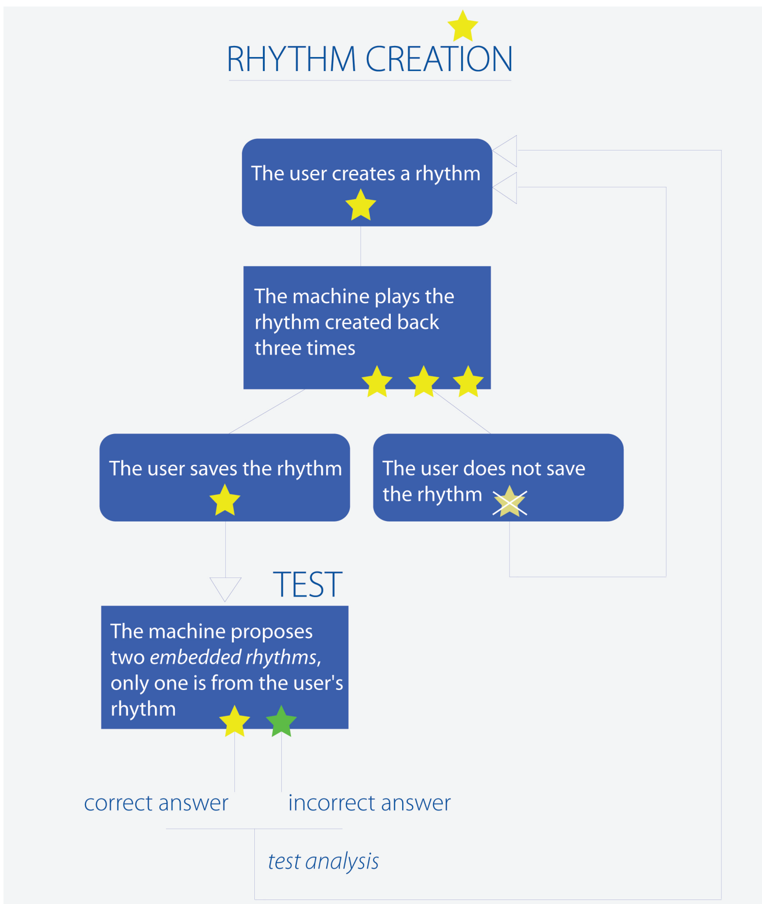

Figure 4-9: **Flow diagram depicting the user interaction with the Embedded Rhythms Generator.**

small sample size of individuals with different disease on the autistic spectrum. Furthermore, the nature of the EFT task and assumptions made pertaining to on-task acquisition of images during task performance is also problematic. However, irregardless of methodological issues, this study exemplifies how EFT differences may relate to gross processing abnormalities in the autistic population. If this is the case, the cognitive strategies differentially employed by autistic and control populations during embedded figure tasks may generalize to other domains.

The embedded rhythms task attempts to adapt the classical EFT for the auditory domain. This is possible due to the hierarchical nature of complex rhythms. A rhythm is a perceptual phenomenon. Constituent excitations, defined within the context of a parent rhythm, interact with one another to form the perceived strength and weakness of any given event in time. The hierarchical structure of a complex rhythm is processed differently than hierarchical structures for other musical stimuli, such as melodies or harmony. Mathematical models identifying perceptual weight of rhythmic units have been research gains to take advantage of unique cognitive processes involved with identifying structures and substructures of the rhythmic object.

In the auditory embedded figures test, users are challenged to identify subrhythms existing within the rhythms that they create. The task is a two alternative forced choice paradigm. The correct subrhythm is generated by randomly selecting a window of notes from the users parent rhythm. The size of the window is determined by the number of notes that the user entered into the rhythm. Currently, the threshold is set so that the test is administered only if the user enters more than two notes for the rhythm. If the number of entered notes is greater than two and less than 6, the user is given two note subrhythms in the embedded rhythms evaluation. For more than five note parent rhythms, the user is given three note subrhythms. After the window size is selected, the window position is randomly chosen for both the target subrhythm and the incorrect subrhythm. The incorrect subrhythm is generated by "bumping" one of the notes from the window either up or down by a sixteenth or eighth notes worth of distance.

50% of the generated incorrect rhythms have a resolution that is smaller than that allowed by the qunatization algorithm. The result is that half of the incorrect rhythms have an additional cue as to their correctness. If the user is not capable of entering a rhythm at the sixteenth note resolution, then they will overtrain on the limitation of the rhythm to eighth note excitations. The presented sixteenth note subrhythm is then heard as different, irrespective of the consideration within the context of the parent rhythm. The evaluation chapter will address issues with the interaction between quantization methods, and incorrect subrhythm generation.

After the user has created their rhythm, and trained on it for three consecutive loops. There is a five second pause before the two alternatives are presented in random order. One subrhythm is presented after another, with a three second interval in between. Subrhythms are accompanied by a light to indicate when they start and finish. After the user has been given both subrhythms, they are able to make a selection on the instruction window by pressing a button corresponding to either the first or second subrhythm.

4.3 Technical Implementation

4.3.1 Max/MSP

The applications were developed using a suite of non-traditional programming tools that make a tradeoff between stability and rapidity of development. Max/MSP is a useful graphical development environment, which is well-known to the audio programming community. Recently, the Max/MSP environment has been extended to incorporate functionality for graphics and text-based programming methods. Graphical and text-based programming features will be described as they relate to the system architecture and development experience.

A Max/MSP application encapsulates functions in graphical objects that hide technical features of the function from the user. For instance, in a Max/MSP program, a developer will never be required to define memory allocations, despite being able to use complex digital signal processing functionality. Functions are stripped down to easy to manipulate essentials, and controlled by a flow of events through a few essential inputs and outputs to the chosen function boxes. As an example, 4-10 shows a simple metronome, coded in the Max environment.

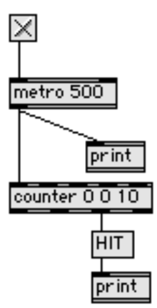

Figure 4-10: **A simple metronome implemented in the max development environment. When turned on, the metronome sends a pulse every 500msec which first flows out the right branch to the print command. Then, a pulse gets sent from the metronome to the counter object, which sends a hit message to print after every 10 pulses.**

The result is like a flow diagram of an application's functions. In the mid-1980's Max/MSP was developed to provide a platform for computer musicians to control events in electro-acoustic music. Through the 1980's, it was extended to interface with synthesizers, samplers, and other emerging technologies of the time. The MIDI protocol allows music hardware to communicate with each other via a data sharing standard. For the discerning composer, in addition to machines being able to synchronize, it is necessary to be able to script the events over which music hardware will communicate. Max emerged as the premier solution to offer control over the MIDI standard for composition and performance purposes.

In 1997 Max was extended with the MSP package. MSP allows the designer to use the graphical interface to directly manipulate audio and perform some signal processing in the same environment that they author control over MIDI information. In 2003, the Jitter package was also added to the environment, allowing the user to control real-time video and handle data matrices.

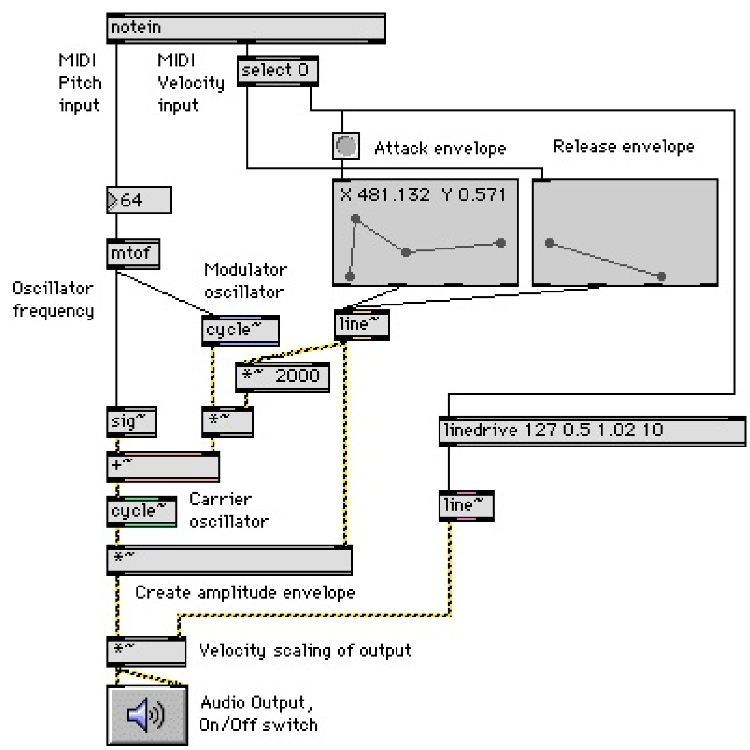

Figure 4-11: **An example of MSP programming from the application, showing objects that perform operations on audio signals, and propegate those signals to the computer's digital audio converter.**

There are several advantages to development in the Max environment. Firstly, an application designer gets functions that very easily interface to a computer's audio and MIDI hardware. Although traditional programming languages have libraries of functions to provide access to a system's audio and MIDI functionality, a designer using these languages would be required to integrate a given library into their development framework. In Max, audio, MIDI and video functionality are included as part of the development framework. Therefore, it is not necessary incorporate external packages for basic MIDI, audio and video multimedia development.

Secondly, since the emphasis of the Max/MSP environment has been on multimedia functionality over years of development, the functions are pre-designed to be useful, which makes development fast. Although external libraries in traditional programming languages allow access to system's audio, video, and MIDI capabilities, the functions available are minimal. They do not typically pre-suppose how or why a designer would want to use them. This offers the maximum possible extensibility, and the minimal amount of immediate usefulness. In contrast, Max/MSP functions have been tailored for composers and audio application designers. The functions they need more often are readily available. As an example, consider the following from one of the applications described in this thesis.

```
function checkTime() {
        var temp_time;
        var diff_time;

        if(!tStart ) {
                tStart = new Date();
                }

        do{
                var temp_time = new Date();
                var diff_time = temp_time.getTime() - tStart.getTime();

                } while( diff_time <= timeArray[timeArray_inc] )

        timeArray_inc++;  //global
        play_tick();
}
```

Figure 4-12: **Function used to get the system time, check against a timer increment calculated from a tempo variable, and conditionally play a note from the array of entered notes.**

```
tsk_1 = new Task(checkTime, this);
tsk_1.interval = tick_time;  //perhaps too large, CHANGE: base on not values

var tStart_pause = null;
var tStart = null;
```

Figure 4-13: **Global timer example.**

The figure shows two timing functions for use in our Melodic Contour task. The functions make reference to several variables that are previously specified in global code: the integer tStart, the integer timeArray_inc, and the array timeArray. These functions are used to play through an array of notes entered by the user. When the function start_play_timer is called, the array *timeArray* is filled with event times in the *for loop* starting at line 5. In this implementation, the piano roll contains 64 possible note positions over two measures. Previously in the code, the tempo was set allowing the calculation of the length of one thirty-secondth note, which corresponds to the duration of one out of 64 possible note positions in two measures. The variable tStart instatiates a javascript date object and stamps the system clock onto the moment the timer was called. Then, in line 14, the function checkTime is called indirectly as the javascript repeating function.

In the *checkTime* function, the variable *temp_time* gets a new system clock value. In line 27, the *temp_time* and *tStart* get subtracted from one another, nested inside a do-while loop. The difference is equal to the time that has transpired between when the start of the timer was stamped and the *temp_time* variable was stamped. At the end of the do-while loop, the difference in system time is checked against the first event time in the *timeArray*. If the compared time is greater than the prescribed event time, the position in the event array, *timeArray*, is incrmeneted to prepare for the next comparison, and a tick is played. The *play_tick* looks at whether or not there is a note in the position of the array corresponding to the event time. The cycle is then repeated until all two measures, or 64 event times and possible note positions, have been checked.

Initially, programming the timer functions to perform relative to the system clock seemed like an optimally fast way of producing accurately synchronized events. Based on the expected interaction between the user and the interface, playback would not be performed simultaneously with other computationally intensive functions. Therefore, it seemed reasonable to use a repeating function, elevated in precedence in the stack of tasks, to execute timed events. The interval at which the function would repeat was set to equal one-tenth of the shortest note duration allowed to be input, at 120 beats per minute. This corresponded to a sixteenth note (125 msecs), and a 12.5 msec repeating interval. However, the following benchmark outline yielded complications with this overall approach to timing by accessing the system clock.

CPU usage was calculated as an average for conditions with various functions and function alternatives both within and outside of the Melodic Contour environment. Usage was monitered with a third party application entitled *App Monitor*, available from Blazing Mouse software. All evaluations were conducted on a Macintosh Dual 2.5 GHz PowerPC 65, with 2GB of RAM, and running Mac OS X version 10.4.6.

With the addition of four Max *metronome* objects each operating at 50msec intervals to output to four openGL windows in Jitter changed the situation considerably. CPU usage averaged at 95% when utilizing the javascript timer function and posting to GL windows. The four metronomes without the javascript timer contribute an average of 28% usage in sum. One metronome alone averages at 16% usage.

4.3.2 Csound

The architecture of the Melodic Contour application navigates between the Max/MSP, javascript and Csound environments. Csound was chosen as a platform to specify detail over the instrument characteristics with a level of specificity that is not available in any other audio development environment. Csound is a programming language in which instruments are specified with functions that give access to predetermined features of the synthesis technique in question. For reference, see [Boulanger, 2000]

As an example, consider the basic instrument in Figure 4-14 which depicts a table-lookup oscillator tuned to 440Hz.

```
                instr 1
a1              oscil   10000, 440, 1
                out             a1
                endin
```

Figure 4-14: **A simple oscillator implemented in csound.**

The oscillator has three variables, corresponding to amplitude, pitch, and lookup function. In the accompanying score file (not depicted), the oscillator is instatied at 0 seconds and plays a sine wave function for 6 seconds.

The developer is free to expand the instrument using functions to change the oscillators variables over time. In Figure 4-15, a line function is specified within the oscillator template to provide a linear ramp to create an ascending and decaying amplitude for the oscillator. The result is a sine wave that begins in silence and gets continuously louder over 6 seconds.

```
        instr 3
a2      linen     10000, .5, 1, .3
a1      oscil     a2, 440, 1
        out       a1
        endin
```

Figure 4-15: **A linear ramp assigned to the amplitude of the simple oscillator example. The order of variables after linen creates a ramp with a maximum amplitude of 10000, a rise time of .5 seconds, 1second duration, and .3 second decay.**

Compiling instruments line-by-line and writing the result to the hard disk is not suitable for the real-time requirements of the melodic contour interface. Csound is integrated into the Max/MSP environment using the csound object, developed by Matt Ingalls. Csound allows Max/MSP to compile Csound files in real-time either by playing the score file when triggered by Max, creating note events in an ad-hoc score file in real-time, or by communicating to csound with midi commands. The melodic generator uses this last approach.

4.4 Summary

The application developed in this thesis embeds Central Coherence measures into novel musical tasks. The first task is the Melodic Contour task. It requires the subject to generate melodies which are then used as stimuli in a delayed matching to sample test. In the delayed matching to sample test, the subject must find the most representative three dimensional contour for their melody. In the Embedded Rhythms Test, a user generates complex rhythms, and then must identify which of two sub-rhythms was present in the rhythm they just created.

The software was authored in a combination of Max/MSP/Jitter, javascript and Csound. This offered rapid development and almost simple access to robust musical and sound design capabilities. Because of the extensibility of these development environments, the graphic, auditory and system architecture needs of the application were able to be fit together with minimal time spent having to develop infrastructure as in digital to audio conversion and memory allocation. However, rapidity of development was paid for with stability. The resulting application requires significant work, and perhaps redevelopment in an environment like java or python, to be stable for distribution to education centers, music therapists, and various other practitioners working with autistic individuals.

Tasks were chosen because of their similarity to central coherence tasks described in the literature. Tasks where local and global processing receive differential emphasis are important to the evolving understanding of antecedents to the social symptoms displayed by individuals with autism. However, the latent opportunity for this work goes far beyond mere description of the local and global processing differences in the population. If these tasks can be shown to identify areas of cognition that are relevant to autism, and simultaneously provide the opportunity for a repeatable task that is engaging, creative, and fundamentally very different than the current implementation of neuropsychological tests, then it is possible to generate cognitive data over time as this tool becomes integrated into novel treatment and education settings. In the next chapter, we will consider issues pertaining to the functionality of the interface, and its use in a context where individuals display symptoms that affect their use of the application. The functional and contextual evaluation, in combination with the implementation of cognition tasks, provides the framework for experimentation and treatment intervention that is the primary outcome of this work.

CHAPTER FIVE

Evaluation

A cognitive training program requires longitudinal research to establish the validity of methods proposed to affect cognitive processes, protect against cognitive decline, or convey skills that transfer significantly into cognitive domains. Unfortunately, experimentation of that nature is beyond the scope of this thesis. For the anatomy of a longitudinal study to address the scientific validity of the proposed central coherence tasks, consult Appendix A.

In addition to scientific validation, the software must satisfy criteria that are general to the needs of the given population, their cognitive abilities, functional abilities, developmental age and interests. These criteria include successful interface design, usability, consistency with expectations, and the ability to sustain interest. To address these criteria, an evaluation was conducted with Matt Lerner, director of the Spotlight Program for young people with Asperger's Syndrome and several of the program's students. This chapter presents the results of the evaluation.

The evaluation consisted of an open collaborative format to encourage discussion about the interface, and to encourage students to take perspective to more accurately provide feedback. The methodology adopted for this primarily qualitative evaluation sought to distinguish systemic and context-dependent criticisms of the user interaction and interface. Systemic evaluation addresses the basic functionality of the interface. Questions directed to the users sought to probe their understanding of the various features they had been introduced to earlier in the session. Systemic questions were evaluated after a "burn-in" period, to give time between the tutorial and when observations were being documented. When observing the users, their success at independently executing various pieces of the interface to construct melodies and rhythms also contributed to the systemic evaluation. Context-dependent evaluation addresses the relationship between the user and the interface that uniquely relates to symptoms of Asperger's disease. For instance, issues related to perspective taking were gauged in questions such as, "what does this part of the program need so that it is useful to other students?"

A behavioral model was not introduced to frame the methodology, interpret data, or predict outcomes for this evaluation because our inclusion criteria were too broad to assume that the users included in the study would going to display consistent symptoms. A behavioral model necessarily assumes consistency amongst the observed population for purposes of statistic description. In retrospect, their were behavioral dimensions of consistency exhibited by the users. Future piloting will quantify commentary indicating perspective taking, time spent independently in each application, successful goal oriented behaviors, and fit them to a factor-analytical model to examine severity of symptoms, behaviors on various aspects of the application, and correlations thereof. A factor analysis is appropriate because the proposed next-generation of pilots will have adequate inclusion criteria and independent measurement of multiple behavior variables.

Seven students were paired with Matt Lerner or myself for thirty to forty-five minutes one-on-one sessions. Two of the students had interest in programming or application development. One of the students had extensive prior experience with composition with commercial music software applications such as Garage Band.

Students first worked with the Melodic Contour Generator, and then the Embedded Rhythms Generator. In some circumstances, students returned to using the Melodic Generator at the end of the session because they expressed that it was their preference. Notes were taken about the student's management of the interface. Discussion with students focused on two categories, interface design, and the applicability of the software to the students interests.

The presentation of results will focus on overall design issues, design issues as they relate to the given population, changes in the interface required for integration into pragmatics interventions, and methods for conducting evaluations with a population exhibiting strong social and communication deficits on the autistic spectrum.

5.1 The Spotlight Program

The Spotlight Program is a clinical pragmatics program for students with Asperger's syndrome. Spotlight is part of the North Shore ARC, a network of residential, family and centre based services for diverse developmental diseases including the autism spectrum. The evaluation of the software was conducted with the director of the program, Matthew Lerner, as part of the Spotlight program's commitment to the adaptation of different treatment methods to fulfill the core elements of the curriculum, namely:

- one-of-a-kind social pragmatics teaching methods involving use of acting games and dramatic training

- positive social reinforcement through strong relationships built between the students themselves
- careful use of strong age-appropriate motivators such as video games and non-competitive physical activity

Furthermore, the Spotlight program identifies goal areas to modulate academic performance in writing skills, reading skills, visual/spatial relations, theatre, and home economics. Curriculum is designed to meet the developmental needs of each individual within the program, through personal assessment of ares related to social symptoms and pragmatic theory, such as: theory of mind, independent conversation, identification of feelings, stress coping skills, body language, receptive non-verbal cues, eye contact, tone of voice, and other areas.

A central focus of the Spotlight program is the use of theatre to structure development in social pragmatics. Social pragmatics are the aspects of communication involving the use of language for different purposes, adaptation of language based on social expectations, and the general adherence to rules of communication.

5.2 Asperger's Syndrome

The students involved with evaluating the software were diagnosed with Asperger's Syndrome. Asperger's Syndrome is a diagnosis within the autism spectrum of disorders. Individual's with Asperger's primarily exhibit impairments in social functioning. DSM-IV criteria are:

A Qualitative impairment in social interaction, as manifested by at least two of the following:

  a marked impairment in the use of multiple nonverbal behaviors such as eye-to eye gaze, facial expression, body postures, and gestures to regulate social interaction

  b failure to develop peer relationships appropriate to developmental level

  c a lack of spontaneous seeking to share enjoyment, interests, or achievements with other people(e.g., by a lack of showing, bringing, or pointing out objects of interest to other people)

  d lack of social or emotional reciprocity

B Restricted repetitive and stereotyped patterns of behavior, interests, and activities, as manifested by at least one of the following:

  a encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity of focus b apparently inflexible adherence to specific, nonfunctional routines or rituals

c stereotyped and repetitive motor mannerisms (e.g., hand or finger flapping or twisting, or complex whole-body movements)

d persistent preoccupation with parts of objects

C The disturbance causes clinically significant impairment in social, occupational, or other important areas of functioning.

D There is no clinically significant general delay in language (e.g., single words used by age 2 years, communicative phrases used by age 3 years).

E There is no clinically significant delay in cognitive development or in the development of age-appropriate self-help skills, adaptive behavior (other than in social interaction), and curiosity about the environment in childhood.

F Criteria are not met for another specific Pervasive Developmental Disorder or Schizophrenia. [American Psychiatric Association, 2000]

The goal of this software is to investigate cognitive discrepancies in central coherence, a processing deficit that has been posited to affect the larger autistic spectrum including individuals with Asperger's Syndrome. At this stage of development, it is necessary to evaluate limitations of the software in terms of usability, interface design, and the changes necessary to create sustainable interaction with the application. To conduct evaluation at this level, a user population was chosen that was devoid of the I.Q. deficit that often accompanies autism. The rationale for this decision was to focus on a population that would expose interface limitations that were unique to the autistic population rather than general to functional limitations of I.Q.. In deciding to focus on a higher functioning subpopulation of the autism spectrum, we were first able to focus on interface issues that uniquely relate to autism spectrum deficits. The assumption is that issues related to interface design and I.Q. deficits are replete in the literature for assistive applications, and are fairly well developed. Furthermore, individuals with Asperger's Syndrome frequently lack the inhibition in communication that one would expect from intact social pragmatics. The resulting interaction, for user-study and design questions, was more likely to suffer from too much information, or irrelevant information. In one student's words from the conducted evaluations, "I'm developing the ability to talk endlessly about this thing."

5.3 The Interface

There were several consistent criticisms from the students regarding the interface design. Firstly, students were interested in the interface being accompanied by an avatar for two purposes: to instruct the student through the use of the program, and to provide feedback for performance on the tasks. The avatar suggestion raises some issues related to social symptoms and the disease. In some cases, the desire for an avatar was linked to the perceived lack of sufficient sensory stimulation provided by the interface. As an example, one student compared the interface to the Animusic DVD series, a highly visual and passive experience, where users watch 3D animations of musician-robots that play impossibly complex instruments in a performance that can only be described as sensory overload. Another student commented that the interface needed, "talking anthropomorphic music notes," to protect against it being, "outlandishly bland and lifeless."

In other instances, users would have rather had an avatar to guide them through a tutorial of how to use the software. In the current evaluation methods, the interface was exposed to the user as part of a social context. It is unclear whether the desire for a tutorial avatar was part of social symptoms regarding the cognitive load of being taught something in a social and open discussion format. Users were not asked whether other students would benefit from being taught the interface by an avatar. It is likely that spontaneous comments regarding tutorial avatars reflect disappointment with the experienced tutorial methods. In contrast, one expert user who had experience with video game design and in interest in pursuing application design as a career, displayed an awareness of perspective tutorial issues through the comment, "I've had you sitting here over my shoulder showing me what to do the whole time, but if you want someone to take this thing home, install it, and have any idea what the heck is going on, you're going to need avatars, buttons with labels, and a completely different interface."

Lastly, avatars were suggested for feedback delivery particularly in the Melodic Contour generator during the contour selection task. Students wished to have access to more information regarding the correct contour, but not the correct In the embedded rhythms task, users make 2 alternative forced-choice selections. After having made the selection, the user receives immediate feedback as to whether or not the chosen subrhythm was present in the rhythm they had originally created. Users seemed content to merely receive feedback explaining whether or not the rhythm they selected as an answer was correct. However, in the melodic contour task, the user receives a matching to sample task, in which they need to choose from four possible choices, all of which are novel abstractions of the user generated melodies. Users were not satisfied with the feedback from the matching to sample task, in which the software suggests that there was a more representative line than the one chosen by the user. The three variables for consideration with respect to the student's feedback are the number of choices, the novelty of the testing stimuli, and language used to inform the user of correct/incorrect choices.

Potentially, the number of choices available and the type of stimuli contribute to the desire to have more informative feedback in the contour task. The embedded figures task requires the user to choose between two auditory alternatives before receiving immediate feedback. With only two choices, it is possible that the users are capable of remembering the rhythm just heard, and not selected, to mentally validate the feedback provided by the software. In contrast, the melodic contour task has two many alternatives and too novel of a stimuli for the user to mentally validate the feedback given by the computer. However, because the feedback for the melodic contour task merely suggests that there was a better choice for abstract stimuli, users might lack confidence in the criteria the software is using for generating answers.

Users were in agreement that they would like more instrument options, but were incapable of offering consistent suggestions as to which instruments they would prefer, and what type of music they would prefer to make. Three instrument selections were possible, piano, an additive synthesis bell, and a granular instrument. Despite being guided through trying all three instrument sounds, users typically used the additive synthesizer sound for the duration of the evaluation. With commentary regarding the desire for more instruments, a suite of available synthesized instruments, and convergence on one instrument for the duration of the evaluation, users may be expressing a preference for traditional instruments. The additive synthesizer was always the first sound presented to the user. Also, it was generally louder than the midi piano, and more pleasant than harsh granular sound. With normalized audio, random instrument selection during the tutorial and better care for the parameters chosen for granular synthesis, it remains to be seen whether users express a preference within the instruments currently available during future evaluations.

5.4 Interface Issues and Perspective Taking

One of the most unexpected findings was the ability of the students to take perspective and consider the usefulness of features of the interface and application for the supposed needs of other children. Throughout the course of the evaluation, when asked questions such as, “Does this arrangement of buttons seem convenient for you,” or, “Do you find it easy or difficult to work in these two different windows to construct your melodies,” students would often not answer the question directly but would mention something like, ”Some people might like the ability to customize the interface; But, you don’t want to overwhelm them with features. Perhaps if they were able to select from three or four different interface possibilities or skins...”

Although this information is valuable, it is a digression from the question asked. The original question required self-reflection to determine the relationship between the individual and the interface aspect called into question. The perspective taking response requires the student to determine the relationship between himself and the interface, imagine another individual attempting to make the same evaluation, assess their knowledge, wants and beliefs, and finally to make an evaluation.

An opportunity presents itself within the digression. Perspective taking is a frequently reported symptomatic area of social pragmatics for individuals with Asperger's Syndrome. It would be reasonable to expect that students would not be capable of making judgments as to the needs or desires of parties other than themselves. However, as observed during the evaluations, this is often the first comment offered by a student. By following a perspective statement with a reiteration of the question that originally required an evaluation of the individual's preference, with increased emphasis placed on the student's own opinion, it is possible to expose where there is a disconnection between the given perspective taking response, and the follow-up self-reflective response. It was frequently found that in follow-up, the students retracted or did not agree with statements they had just made with perspective when confronted with reiteration of their own opinion. For instance, in reiteration, the student who had initially commented about, "three or four different possible skins," when asked about whether they would find skins useful replied, "No, I don't think so." In another example, a different student commented, "I think kids might want more choices for length of the entry window." When asked, "would you want more choices for the length of the entry window," the student replied, "It wouldn't matter either way. No."

Matt Lerner offered an opinion as to the paucity for perspective taking. He contends that individuals in the Spotlight program, who receive an intensive focus on developing social pragmatic skills, which include perspective taking, do have the ability to begin considering others needs, beliefs and knowledge. The lowest functioning student in the group, both cognitively and socially, did not offer perspective at any point during his evaluation. In contrast, many of the students who were the most persistent with perspective commentary were older students, who were higher functioning and had been involved with Matt Lerner and pragmatics training for several years.

Due to perspective taking discrepancies in the Asperger's population, strategies need to be introduced to defend against erroneous reflection given by a user who is hyper-verbal, yet possibly inaccurate in their consideration of the needs and preferences of the general public. One strategy, is to reflect the individual's perspective assumption while requesting the user to make the evaluation for themselves. Another strategy is to ask direct questions, with discrete answer choices. Questions with discrete answer choices are not as useful in the initial stages of testing interfaces compared to an open discussion format. An open discussion format is capable of revealing new questions that were not immediately obvious to the designers. Requiring the user to select from answer choices pre-supposes many assumptions as to the interface issues in question, and constrains the user unnecessarily into imagining several possible directions of the software. However, the lower functioning individuals, both cognitively and socially, were not able to offer opinions in open discussion format. When asked questions such as, 'Could you imagine this software as part of [SimTunes]," or some other game with a composition component that the student reported playing in the past, the student would not respond, make an off-task remark, or say, “I don’t know.” This seems to be consistent with the student’s difficulties to re-contextualize as evidenced in their Spotlight Program performance.

5.5 Repurposing for Intervention

When asked which part of the application would the student like to revisit a few days from now, the group was equally divided in preference for the creation of melodies, assisting the computer to choose appropriate contours, and, “playing the embedded rhythms game.” However, user preference was extreme where if a user was interested in the embedded rhythms task by the time we concluded with the guided use of the application, it was at the exclusion of all else. Exclusivity of preference was not exhibited by the lowest functioning individual in the group. A students exclusive preference was the focus of their commentary after both interfaces had been presented and the student was encouraged to discuss whichever part of the application they found the most worthy of discussion.

Program director, Matt Lerner, has commented that users may show a bias for melodic versus temporal processing as evidenced in activities involving audio as parts of the curriculum offered at the Spotlight program. The evaluation was directive. Users spent the majority of their time with structured guidance through the interfaces and in discussion. It is premature to suggest that exclusive preference may have related to insistence on sameness, which has been identified as a symptom of Asperger’s Syndrome. On the contrary, users did not show any difficulty switching between drastically different melodic and temporal tasks over the course of the evaluation. In considering adaptation of the interface for incorporation into an intervention for this population, it may be necessary to provide a mechanism for the different domains of auditory processing to interact in the creation of music. Although it is unclear how to blend disparate rhythms and melodies, once the central coherence condition has been fulfilled, the user should be encouraged to combat their exclusive preference and encompass a more holistic approach to using the features available.

None of the students were interested in the collaborative composition interface proposed for the context that the Embedded Rhythms Generator and Melodic Contour Generator would eventually be a part of. Comments included, “I guess that would be helpful for teamwork and everything, but it’s a cruel, cruel world out there. I’d rather do this stuff at home,” and, simply, “I’d rather work on my own.” This may be due to the difficulty to extend the one-on-one evaluation format to the group condition. However, it was the only question which each group member responded to identically. The broad goal of music interaction is that it provides a framework to structure social learning. Although the present implementation does not contain a social component, it was designed with modules that could be easily integrated into a collaborative performance or composition environment. Perhaps, collabrative composition is too ambitious. Where social pragmatics are involved, performance may be the better model with which to frame repurposing of the current tools to garner a social benefit.

Collaborative performance fits within the expectations that a user would have for groups of musicians contributing in real-time. In future evaluations, to measure the user's interest in the proposed future implementation of designed modules, the hypothetical context should be presented in a way that it fulfills more of the user's expectations regarding the use of stimuli similar to those employed in the modules.

5.6 Adaptability

One advantage of generating quantifiable cognition data as part of the user interaction is that the interface can adapt itself based on user performance outcomes. Adaptation can be structured to facilitate the user's performance in the form of tutorials. Many of the users expressed a desire for avatar interaction to assist with learning the interface. However, it is unclear which performance indicators are salient enough to conditionally introduce tutorial support after the initial introduction to the software. For instance, if a user spends less time using a certain feature it is not necessarily because they do not understand its function. Then again, it may be. Some users progressed through the entire set of possible note features in the multi-feature contour environment, but when left to their own devices, tended to adhere to a small subset of features. In the case of instrument selection, user's reported that this was due to preference. In the case of timbre selection, it may be that the function of the timbre feature was obfuscated from the user because the relationship between turning a knob and changing arbitrary features of a sound is unclear .

In a longitudinal neuropsychological tasks, to protect against ceiling and floor effects, it is possible to modulate the interface to become more accessible or more challenging to the user. In the melodic task, users who show greater proficiency over time, as measured by the number of correct contour selections, should be able to unlock new stimuli dimensions of the same test. For example, the current melodic contour test requires the user to encode two dimensions, pitch and time, that get directly mapped to a three dimensional image. Other features of the sound, such as brightness, roughness, and volume, are not currently part of the melodic contour test. Based on user performance in the pitch and time condition, it is possible to introduce other variables to effect width of the three dimensional line, color, or smoothness. This is more appropriate then, say, allowing the user to manipulate more note features as a function of performance. The cognitive load implications for incrementally adapting the cognitive assessment component of the interface to incorporate instrument brightness, roughness, and volume are separable from preference. In contrast, allowing the user more feature selections does not ensure that they will use those selections over established preferences to incur more cognitive load.

5.7 Summary

Overall, the students of the Spotlight Program displayed an amazing willingness to offer perspective on the value of the interface for different populations. The accuracy of perspective with respect to the individual's personal evaluation is potentially a fruitful avenue of independent study. User's expressed difficulty in considering the application outside of the immediate context provided by the evaluation.

During this evaluation, it became clear that the initial phase of research to determine the validity of the application compared to the traditional neuropsychological measures upon which it is based should be conducted independently from the interface design process, at least at first. There are basic research questions that are yet to be answered related to delayed matching to sample tasks for auditory and visual stimuli, use of user generated stimuli, and control between musically literate subjects and those who would not normally self-select for music tasks. However, this evaluation has shown that in consideration of the interface, and the user's relationship to the interface, complex issues regarding perspective, application functionality, and task preference for novel musical technologies used by a clinical population are equally interesting. Broad implications for the scalability of creative applications exist in further investigating the design of the interface as it relates to a user's symptoms. In the future, subjects with Asperger's Syndrome and autism will be completely integrated into a collaborative design process, not as users but as colleagues.

CHAPTER SIX

Conclusion and Future Work

6.1 From Reductionism to Collaborative Opportunities

The presentation of music as a sum of discrete, constituent parts, is slightly problematic considering the larger role, both aesthetically and creatively, by which music can impinge itself upon a person. Certainly, the strength of music from a social perspective, and potentially, from an evolutionary perspective, are disserviced by this type of mechanistic reduction. However, a reductionist perspective for the sake or quantifiable measure, and potentially, cognitive description, does not deny the opportunity for music to act upon an individual in ways that are more meaningful than what we may describe through research. In designing an interface that abstracts music into units that are useful for cognitive inquiry, the commitment remains to develop the interface in a context that allows for creative expression. A user must be able to access, beyond a set of reduced musical features, the larger role of musical experience and creative opportunity. Herein lies the difference between working with audio and working with music. Auditory training as it is described in auditory plasticity research is limited in its applicability to truly creative interventions. Those that work on cognitive training using low-level auditory stimuli to drive performance in areas such as motor function, are hard pressed to derive a musical context that is substantially more meaningful than drum pulses, metronomic repetition and tone pips. By designing cognitive tasks that are reasonably discrete, and having the results of those tasks propagate into larger composing and performance environments, interventions are possible that develop evidence measures, seated in cognitive regions of interest, while fostering the contribution to something aesthetically robust and creatively interesting. Auditory training is hard pressed to find such an application.

The primary emphasis for future work regarding this research is a broader creative environment for the melodic contour task and the embedded rhythms tasks. The result of generating rhythms and melodies by a user of these modules is the development of a library of musical material. The future direction of system development is flexible as to how it can integrate these musical units into collaborative environments. Despite flexibility in exactly how the produced melodies and rhythms are integrated into a larger system, there are three broader goals:

- To facilitate social interaction through music interaction
- To measure social behavior for correlating with generated cognitive measurement
- To provide motivation to participate in cognition tasks by shifting the goal to a broader musical accomplishment

The proposed system would require subjects to bring their libraries of pre-composed musical motifs (rhythms, and melodies), to the session. Users would then plug into a collaborative performance system like what is loosely depicted in Figure 6-1. Sections of the performance would loop repeatedly, giving users the opportunity to drag their musical motifs into a multi-track environment, where the contributions of the users are layered on top of one another to create a musical collage. The looped section would be short, perhaps only several measures of music. By keeping the looping section short, users have the opportunity to hear how their musical contribution fits the layered material from other users, and make adjustments accordingly.

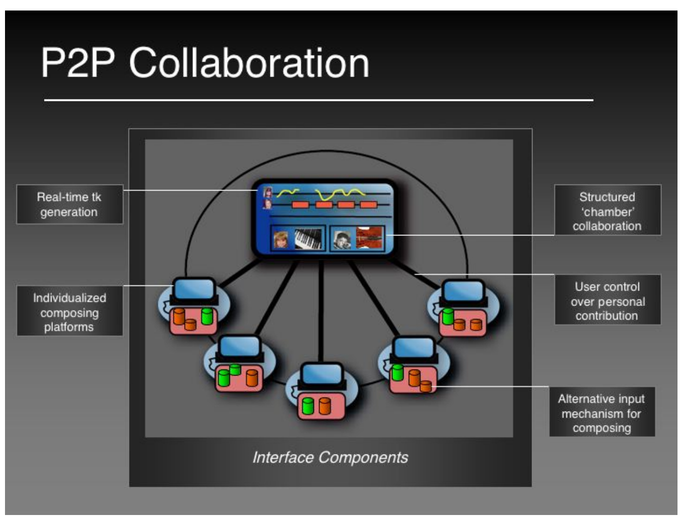

Figure 6-1: **The proposed context for the developed melodic contour generator and embedded rhythm tasks - a collaborative composition and performance environment facilitating group music making with the user's previously generated melodic and rhythmic material.**

A system that removes an autistic individual from a direct social interaction and provides them with a facsimile thereof may deny that individual an opportunity to develop strategies to combat their symptomatic social behavior. To address this issue it is necessary to provide features that shift the experience from a potentially isolating social microcosm to a supportive environment that fosters social perspective, joint attention, social timing, cue reading and other socializing behaviors. To provide this shift, investigating the use of avatar's is most appropriate.

The key to altering the collaborative experience so that it supports social interaction beyond the musical output will be driven by avatar use and facilitation by a super-user. Avatars are useful for the general population to convey information in a microcosm of a social context, and to assist in social collaboration. They may be helpful in the proposed collaborative environment to attribute ownership of contributed information and facilitate the subjects to work with one another. Social and collaborative facilitation can also be provided by the super-user, by implementing functions that request for subjects to solo with one another, or otherwise directly acknowledge one another's contribution in some more directed fashion.

Behavioral measurement of social factors in this environment can be achieved by measuring the frequency of contributed material, the amount of time a user has any material in the looping section, the frequency with which an individual accepts invitations from the super-user for more direct social interaction, and amount of time spent with on-task behaviors including attending to the system with or without input. If the system is able to capture these behavioral markers, it is possible to conduct longitudinal research to try and correlate social behavior, as measured by the collaborative system, with changes in the cognition data, as measured by the melodic contour and embedded rhythms tasks.

There are several questions that require resolution for this system to work:

- To what extent do avatars supersede underlying issues in social perspective and theory of mind?
- Should the system emphasize collaborative *composition* or collaborative *performance*?
- What can be done to manage attention to task in a group environment with less behavioral facilitation than traditional education and activity groups for this population?
- What are the limits of a traditional computer interface for entry with autistic individuals rather than high functioning autists and individuals with Asperger's syndrome?
- How is material labeled in a large user-generated library of melodies and rhythms, so that it can be readily remembered and used in the collaborative system?

6.2 Integration Into Current Treatment Practices

The melodic contour task and embedded rhythm tasks are being incorporated into the treatment and education programs of practitioners in the Boston area. Our evaluation of the melodic and rhythmic modules stems from early efforts to examine the appropriateness of the modules for incorporation into current treatment and intervention practices. The success of this initial phase of evaluation is the finding that the melodic and rhythmic modules are capable of being utilized by therapists and educators as part of already established broader music and social contexts that are adaptable to include novel forms of media, both musical and visual.

In another example, in collaboration with Salem music therapist Krystal Demaine, BC-MT, NMT, research is underway to investigate whether the melodic and rhythmic tasks can dissociate between the functional abilities of musical savants with differential talents in temporal versus pitch perception. The high prevalence of savant-like abilities within the autistic population is well established[Kehrer, 1992, Mottron et al., 1998, Pring and Hermelin, 2002, O'Connor and Hermelin, 1991]. Furthermore, many patients display savant abilities in music and the arts. The opportunity this affords is to examine questions such as: what are the differences in prodigies with disproportionate abilities in one or several clearly delineated functional domains, how do they acquire domain specific musical literacy, are there correlating functional discrepancies, are there neurally describable morphological differences? The first step in this line of inquiry implies implementation of the melodic contour and embedded rhythms task, in addition to a suite of other neuropsychological tools, to better describe the dissociable demographic. This line of inquiry could lead to more neuroscientific methods to elucidate underlying structures of interest in the autistic population based on differences in temporal and hierarchically organized melodic stimuli.

We are also examining the suitability of the current physical interface for a broader spectrum of autistic individuals, including those with severe intelligence deficits in addition to their primary diagnoses of autism. A computer screen, mouse and keyboard are not implied for individuals with severe motor dysfunction as part of their autism symptoms. Physical interfaces where children can participate in the tasks outlined in this thesis utilizing tangible interfaces could significantly broaden the scope of this work.

6.3 Final Remarks

It is obvious that new technologies inform the potential for human development. Our concept of ourselves, our relationship to the world, and to each other is modulated by those interfaces and applications that become part of our lives.

The expression of creativity, given life by the tools we use, is intrinsically linked to the limits and possibilities inherent to the tool.

A new field is emerging, where the understanding of the biological mechanisms underlying plasticity, learning and memory, is inspiring researchers and technologists to consider how new applications may sculpt the neural substrates by which we define our capacities. The future of health lies in the dynamics of the brain, and the potential for the brain to change with structured experience. The question is how to structure experience so that newly discovered biological mechanisms can be efficiently and consistently targeted for the betterment of health. The answer is with new technologies, built with design principles derived directly from scientific literature. The answer is also with music, the artifact that persists at every stage of human development for as long as there has been record, the multistoried object with infinite levels of structure, the one tie that binds the mechanisms with which we define ourselves.

APPENDIX A

A.1 Purpose of Longitudinal Study

Although clinical practitioners and therapists have been using music as a therapeutic tool for patients with autism spectrum disorders, recently published third party reviews raise substantial questions as to flawed methodology, limited scope and unjustified evaluation criteria for these therapies. Even more problematic is the lack of scientific understanding as to how or why music is effective as a treatment. No one has yet been able to systematically study the components of music and cognition that change over time during the complex clinical use of music. This author believes that such a disconnection between science and clinical effect is unacceptable. The questions addressed by this study are: how does one scientifically quantify what is taking place, cognitively, physically, and creatively during music making in the clinical environment; and what tools, techniques and activities might be developed to best leverage these findings? To do so, we have developed simple, controlled, music activities that evaluate cognitive performance in memory, and visual tasks. We hypothesize that it is possible to track cognitive performance over time, and correlate that data with observed behavioral change as musical tools are used as part of music activities for autistic populations.

A.2 Study Protocol

There are two components of this exploratory research. (1) First, we need to determine which cognitive domains are appropriate for measurement as part of musical tasks. We suggest that tasks that are meant to distinguish between local and global processing will be efficacious for our study. Autistic individuals have shown deficits in this areas of processing for vision, memory, and auditory tasks. Our tasks allow a subject to compose rhythms and melodies, which are then turned into representative images by software we have developed. The subject is asked which of the images is the best fit for the auditory object they had initially created. The representative images are global, in the sense that they are abstractions from the originally composed material. The system also asks other questions about what has changed in the auditory object. An example question would be, “Which of these lines is the most like the melody youve just made? An example instruction would be “Pick the rhythm that was part of the rhythm you just made.

After completing these music creation tasks, a file is written linking the performance on the musical tasks to de-identified subject information. The de-identified subject information strictly pertains to the musical past of the subject and contains no information about sex, place of inhabitance, name, clinical profile or other protected health information. Questions include, how often the subject listens to music, whether they participate in any music groups at the hospital, whether they take music lessons, etc. A returning subject is identified in the system by a number that only he or she, and the clinical director at McLean, have access to. This way, subsequent performance data can be linked to the history of a users performance. Repetitive performance on the same test is required to evaluate whether or not the designed tests are robust to show performance change over time that is different than the expected improvement due to simple familiarization with the musical task.

There will be eight sessions per subject, scheduled at their convenience over a several week period. Sessions will last no longer than 30 minutes. Sessions may be terminated at any time by the subject or at the discretion of the attending clinician.

(2) Secondly, we need to build these tools into a music composition suite that can be used as a group task. The group task allows subjects to load pre-composed melodies and rhythms into a looping, real-time sequencer that creates layers of melody. This is meant to be analogous to what music facilitators traditionally do when conducting groups of autistic children to compose and perform music. The difference is that we have designed software to automate the process, and record how frequently subjects offer material to the system. The unique opportunity of the group condition is to perform behavioral measurement. Since the music performance task requires social acumen, as in the collaboration of multiple individuals to create a working piece, it becomes an environment suitable to measure social behavior as evidenced by the frequency that a subject submits and/or withdraws their material. Performance of these behavioral measures will be analyzed in comparison to performance on the cognitive tasks. Since it has been hypothesized that autism is potentially rooted in the type of local versus global processing deficits we are investigating in the first part of this procedure, we contend that changes in behavior in the music performance condition will correlate with changes in cognition as recorded in the melodic and rhythmic tasks. Repeat group measurement will also be encoded numerically, linked to music-demographic information, and stored as described later in this proposal. The subject log and numerical keys will be kept by the clinical director at McLean.

There will be eight sessions per group. Sessions will last no longer than 45 minutes. Sessions may be terminated at any time by any of the subjects in the group or at the discretion of the attending clinician. Sessions will be conducted over several months and scheduled at the convenience of the group participants. Support staff from McLean will number as necessary to insure that the participants in the group are safely able to contribute to the group without risk of harm to themselves or others.

(3) Other protocol issues: All audio is delivered to the environment, through computer speakers, at levels controlled by the attending clinical support staff at McLean, and in consideration of hypersensitivity counterindications as outlined in the risks/discomforts section of this proposal. All levels can be adjusted at the subjects request, although adjustments defer to the attending clinicians judgement.

The patient log is irrelevant to the analysis of data in this study. It is kept only to facilitate linking of performance to music demographic data in the case that the user forgets their number. Because of its research irrelevance, it is kept along with patient records that are of importance only to the clinical staff at McLean, at the site.

Experimentation will be conducted by research assistant Adam Boulanger, and staff at McLean hospital. Adam Boulanger has received a BA degree in music therapy, and is qualified to administer musical tasks and activities to pathological populations, including individuals with autism and children with developmental disorders. Also, Adam Boulanger has received additional training by McLean hospital to familiarize him with the specific risks and needs of their clinical population.

The software used to introduce and record the stimuli of this study was built so that users can record their ongoing performance on their own time, with minimal interaction with the experimenters. After a subject has shown facility with the experimental protocol, following several sessions of supervised use, experimentation will be conducted by the subject with only the supervision of clinical support staff. The subject can self-select to use the software at their own convenience.

McLean hospital staff will be present during experimentation. McLean staff will be relied upon to facilitate subject compliance with the research protocol, in addition to the management of safety precautions. The educational emphasis of the Center for Neurointegrative Services at McLean hospital clusters children with similar learning profiles in order to facilitate group learning and group activities. As a result, the staff is qualified to facilitate the group activities that we propose within this study. Staff-to-student ration is 2:1. This rato will be consistent with the staff support for this study.

A.3 Human Subjects

A.3.1 What are the criteria for inclusion or exclusion?

The main inclusion criteria will be a diagnosis (made by Dr. Gold) of autism or Asbergers syndrome. Subjects will primarily be recruited from the Center for Neurointegrative Services: Pathways Academy, a comprehensive day school for children age 6-22 with Asbergers syndrome and related disorders. Subjects must be verbal and capable of following written instructions. A total of approximately 14 subjects per month will be recruited (7 control subjects and 7 subjects with either autism or Asbergers disorder). Control subjects will be of similar age range to the experimental subjects. Control subjects will primarily be recruited from family members and friends of the members of the Pathways program community.

All subjects will be carefully screened for a behavior profile that is conducive to the proposed study. Careful screening for disruptive behavior, auditory hypersensitivity, and violent reactions to interpersonal communication will be conducted via questionnaire with the individuals parents and behavioral assessment conducted by educational staff and the resident neuropsychologist at the Pathways Program.

A.3.2 Are any inclusion or exclusion criteria based on age, gender, or race/ethnic origin?

No subjects will be excluded on the basis of sex, ethnicity, or race.

A.3.3 Explanation of any vulnerable population, and why that population is being studied.

The vulnerable population implied by this study is children, under the age of 18, with the diagnosis of autism or Asbergers Syndrome. Asbergers Syndrome is a subcategory of autism. Autism and Asbergers Syndrome are pervasive developmental disorders with primary deficits in social interaction, communication, and highly repetitive behavior. Unlike children with autism, children with Asbergers syndrome display IQ that is typical for their age or above average. Both groups display social and communication deficits.

This population has been identified for this study because, currently, very little is known regarding the cognitive performance features that underly complex disabilities social behaviors and communication. To date, there have not been significant neuroimaging or neuropathological findings that can consistently be contributed to the observed cognitive and behavioral profile of individuals with autism or Asbergers Syndrome. As a result, basic science research is required to identify, not only the domain specific cognitive profile of individuals with these diseases, but, more importantly, how that cognitive profile changes over time. This study will develop the tools and methodology to embed this type of cognitive assessment into novel applications such as musical composing tools.

We have chosen children for this study because of the unique developmental prognosis for individuals with autism and Asbergers Syndrome between the ages of 8-18. It is typical for a child with autism to develop language only in their seventh year of life. After this, recent research indicates that the following few years represent a window of opportunity to develop coping strategies and improve other aspects of perception and social interaction. In adulthood, the developmental and behavioral prognosis for this population is inadequate for our investigation. We measure cognitive change as it correlates to behavior change. It is necessary to measure cognitive performance in the window of time where the individual with autism or Asbergers Syndrome is likely to show behavioral development. Our control for behavioral development and ancillary education is that children from the Pathways program are clustered to receive similar treatment and education services depending on their cognitive abilities and social needs.

A.3.4 Subject recruitment

McLean already provides music therapy services in addition to music activities for many of the students in the Pathways program. McLean personnel will identify individuals who show an interest in the music activities already available at the Pathways program. Parents of the identified individuals will be given material describing the study, and asked if they would like to enroll their child. Subjects will only be selected with voluntary informed consent of both the minor and the parent.

Control subjects will be recruited from family members and friends of students in the Pathways Program. Prospective students and their parents will be given material that describes the putpose of the study, its experimental procedure, risks benefits and proposed outcomes.

A.3.5 Potential risks

There are no potential risks inherent to the music tasks and music tools utilized in any part of this study. They are non-invasive musical activities. The autistic population as well as those with other pervasive development disorders suffer from debilitating social pathology, that sometimes causes psychological stress from what would otherwise be considered innocuous social interactions. The risk of mental strain on the subject population due to experimentation is the most significant discomfort possiblity. Although, it should be noted that autistic individuals show a wide range of reactions to interpersonal communication, and cannot be stereotyped in their receptivity and reactions to interpersonal communication. Secondly, some autistic individuals show a hyperacuity in the perception of sound, light, and other sensory information. Thirdly, some autistic individuals display behaviors that are considered innappropriate or disruptive.

The clinical staff at the McLean Hospital are trained and specialize in developmental neuropsychology. Furthermore, the clinical staff is integrated into the academic and clinical treatment programs at the hospital and will be an integral part of subject selection and safety compliance. The staff will be relied upon during subject recruitment, experimentation and follow-up to ensure that appropriate subjects are identified given the interpersonal communication requirements of the proposed study. Furthermore, where ambient speaker introduced auditory stimulation is contraindicated due to hyperacuity, McLean staff will screen the subject from the experiment. Any experiment of this study can be discontinued at any time during the study, for any reason of discomfort or at any side of risk. The risk of psychological stress due to interpersonal communcation is minimized by the software designed for this study, which delivers most stimuli autonomously and separate from any interpersonal requirement. Also, MIT personel conducting experiments at McLean have received additional training at McLean as to the clinical protocol and risk management for the given population. Where subjects have been identified by McLean personnel as having diruptive or innappropriate behaviors, subjects will either be withdrawn from the experiment or additional McLean staff will be included to ameliorate these behaviors through direct assistance, and ensure that they do not interfere with the epxerimenting staff or other participants.

A.3.6 Potential benefits

The subjects do not stand to receive any potential benefits aside from the opportunity to make music.

This study will aid in the basic understanding of auditory cognition and autism spectrum disorders, as well as providing a framework for the development of new tools that can potentially measure cognitive function as part of music composing tasks. The potential benefit is significant because the ability to define cognitive profile as part of the tools we use could lead to therapies that are adaptive and personalized, ensuring maximal efficiency of treatment.

A.3.7 Data collection, storage and confidentiality

Performance on experimental tasks will be recorded by the software developed to run the experiments of this proposal, and stored on our lab computers.

All data will be coded to dissociate it from any personal identifiers. Demographic information will be stored along with performance data. None of the demographic data falls under the definition of protected health information, nor can it be used to identify individuals. Demographic data is used solely to guage the amount of prior musical experience a subject has. The experimenter's subject log will be kept locked in the office of the head of the collaborating McLean program, where subject recruitment and scheduling is exclusively handled.

Data will be stored on computers at my lab. All computers in the lab used for storing data use standard athena security patches. Also, the lab computers only contain de-identified information, so there is no possibility of linking to specific individuals.

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