SPEECH AND MOTOR CONTROL IN CHILDREN WITH DOWN SYNDROME

SPEECH PERCEPTION AND MOTOR CONTROL IN CHILDREN AND ADOLESCENTS WITH DOWN SYNDROME

By

LINDSAY BUNN, B. KIN

A Thesis

Submitted to the School of Graduate Studies

In Partial Fulfillment of the Requirements

For the Degree

Master of Science

McMaster University

MASTER OF SCIENCE (Human Biodynamics)

McMaster University
Hamilton, Ontario

TITLE: Speech Perception and Motor Control in Children and Adolescents with Down Syndrome

AUTHOR: Lindsay Bunn, B. Kin. (McMaster University)

SUPERVISOR: Dr. D. Elliott

NUMBER OF PAGES: vi, 65

Abstract

Twelve children without intellectual disability and 12 children and adolescents with Down syndrome were administered a short form of Roy and Black's (1998) Apraxia Battery. Participants with Down syndrome also completed a free-recall dichotic listening test. While the mean laterality indices for the group with Down syndrome was negative, indicative of a left ear-right hemisphere specialization for speech perception, they were not significantly different from zero. There was a wide range of individual variability in laterality, and individuals with a left ear advantage for speech perception performed more poorly on the portions of the apraxia battery that involved verbal instruction. The possibility that individuals with Down syndrome who have apraxia may constitute an important subset of individuals with Down syndrome was considered. The results are discussed within the framework of Elliott, Weeks, and Elliott's (1987) biological dissociation model.

Acknowledgments

First, I would like to thank the children who participated in this study. It was them that kept me going during my equipment failure, my poor sense of direction in Vancouver (where it rained for almost 10 days straight!), and the days when I wondered why I was doing this! I enjoyed spending time with each and every one of you.

I would like to also thank the parents of the participants who managed to find the time to fit me into their very busy schedules. Many welcomed me into their homes and expressed a very genuine interest in what I was studying. Without your support this research would not have been possible.

Thank you to Kim Pace for her expertise in speech, language and communication as well as for her help recruiting participants.

Thanks also to the Hamilton Down Syndrome Association for their support and the opportunity to discuss with parents research on speech and motor control in children with Down syndrome.

Thanks to Eric Roy who met with me on several occasions to discuss the apraxia battery portion of my thesis. Thank you for going above and beyond your duties as a committee member. I enjoyed visiting Sunnybrook and learning more about apraxia.

Thank you to Sheryl Dickson, Jo Mills and the rest of the staff at the Down Syndrome Research Foundation in Burnaby for their help with participant recruitment. I appreciate you welcoming me into your new facility at such a busy time.

A special thanks to research assistants Victoria and Cheryl who spent countless hours watching video tapes and scoring participants. I appreciate both your thoroughness and enthusiasm. Good luck wherever life takes you in the future.

Last, but definitely not least, I would like to thank Digby Elliott who gave me the independence I enjoy but was always available when I needed him. His generosity, kindness, and patience make him a spectacular supervisor and his students both privileged and down-right lucky.

TABLE OF CONTENTS

Introduction

Over the last two decades numerous studies have been designed to examine cerebral specialization in Down syndrome (see Chua, Weeks, & Elliott, 1996 for a review). These studies, involving both non-invasive neuropsychological techniques such as dichotic listening (Elliott, Weeks, & Chua, 1994) and the examination of manual asymmetries (Elliott, 1985), and more recently, research using neuroimaging (Gaetz, Weeks, Chua, Weinberg, Welsh, Elliott, submitted; Weeks, Chua, Elliott, Weinberg, Cheyne, & Lyons, 1997), have been instrumental in our understanding of the unique pattern of cerebral specialization observed in individuals with this karyotype. As kinesiologists, many of the studies first conducted in our lab focused on the control of limb movements in children and adults with Down syndrome. While conducting these studies researchers began to notice that the difficulties experienced by individuals with Down syndrome were often verbal-motor in nature. These findings along with the results from early studies of dichotic listening in children with Down syndrome (Hartley, 1981; 1982; Pipe, 1983; Zekulin-Hartley, 1981) set the stage for the beginning of a research endeavor that Elliott and colleagues have been working on since the mid-1980's.

The purpose of the present study was threefold. The first purpose was to examine cerebral lateralization for speech perception in children with Down syndrome using a dichotic listening technique. A second purpose was to investigate if cerebral lateralization for speech perception, as determined by performance on a dichotic listening test, is related to performance on a short form of Roy and Black's (1998) apraxia battery. This is a test that measures several different facets of perceptual motor control. A final purpose was to complete a preliminary investigation of the role of speech and music therapy in remediating speech difficulties in children with Down syndrome within the framework of Elliott, Weeks, and Elliott's (1987) biological dissociation model.

A Biological Dissociation Model

In 1987, after reviewing previous research, Elliott and colleagues proposed a model of atypical cerebral specialization that differed in one major way from an earlier theory by Hartley (1981). Hartley originally suggested that individuals with Down syndrome exhibit a reversed specialization for speech. From the results of studies involving paradigms other than dichotic listening that were designed to target motor control processes (e.g. Elliott, 1985; Elliott, Edwards, Weeks, Lindley, & Carnahan, 1987), Elliott et al. (1987) suggested something different. They proposed that individuals with Down syndrome do not exhibit a reversed specialization for speech in general but a reversed specialization for speech perception. That is, while individuals with Down syndrome usually have a unique right hemisphere specialization for speech perception, they are left hemisphere specialized for the organization and control of movement, including speech movements, much like many people without Down syndrome.

Since 1987 many more studies have supported the notion of a biological dissociation between the neural systems specialized for speech production and the systems specialized for speech perception in individuals with Down syndrome (Heath & Elliott, 1999; LeClair & Elliott, 1995; Piccirilli, D'Alessandro, Mazzi, Sciarma, & Testa, 1991). For example, Heath and Elliott (1999) used a mouth asymmetry technique to examine lateralization for speech production in adults with and without Down syndrome. Investigators found that, for both groups of participants, the right side of the mouth opened sooner and wider than the left side of the mouth during speech production. This suggests that the left hemisphere is more involved in speech production than the right hemisphere. Elliott et al.'s (1987) model therefore, only posits an atypical or reversed specialization for speech perception. Similar to the general population, speech production and the control of limb movements tend to be specialized to the left hemisphere in persons with Down syndrome.

Movement and Verbal/Visual Differences in Instruction

A functional dissociation between the areas responsible for movement organization and speech perception in individuals with Down syndrome has many implications for the control of movement, including speech movements. Elliott, Weeks, and Gray (1990) asked adult participants with Down syndrome, as well as adults of similar chronological age and receptive language ability who also demonstrated intellectual impairment, to produce single movements and sequences of movements following visual and verbal instruction. The results of this study illustrated that adults with Down syndrome made more errors following a verbal cue than a visual cue. This evidence provides support for Elliott's model of atypical specialization for speech perception in individuals with Down syndrome. This model predicts verbal-motor problems in individuals with Down syndrome when instructions are verbal because of the degradation of information during interhemispheric communication.

In another study Elliott and Weeks (1993) examined the relationship between performance on the same apraxia battery (Kools, Williams, Wickers, & Caell, 1971) and dichotic listening performance. Adults with Down syndrome exhibited a LEA for the perception of speech, as determined by a dichotic listening test. They also produced more errors on the apraxia battery when instructions were given verbally rather than visually. Elliott and Weeks (1993) also found that the more right hemisphere lateralized an individual with Down syndrome was for speech perception, the more errors he/she made on sections of the apraxia battery that were given verbally. The research reported in this thesis follows directly from the Elliott and Weeks study. There were three main differences: 1.) The participants in the present study were children rather than adults. 2.) The relationship between speech and music therapy, movement execution and ear advantage in participants with Down syndrome was explored. 3.) The research presented here utilized a much more comprehensive apraxia battery designed to examine several different aspects of movement.

Neuroimaging and Cerebral Specialization for Speech Perception

Most of the support for Elliott's 1987 model has originated from studies employing various noninvasive neuropsychological techniques. More recently, researchers studying cerebral specialization for speech in Down syndrome have started designing protocols using neuroimaging technology. Many studies employing various structural neuroimaging techniques provide support for Elliott's model. For example, studies using MRI, a more spatially accurate structural imaging technique than Computed Tomography (CT), found that important areas of the brain implicated in language perception, such as the Planum Temporale and the Superior Temporal Gyrus, were volumetrically different in the brain of persons with Down syndrome (Gaetz, Weeks, Chua, Weinberg, Welsh, & Elliott, submitted). These language areas appeared to contain less white matter. Other researchers, utilizing MRI, report that individuals with Down syndrome have a smaller, more rounded and rostrally thinner corpus callosum (Wang, Doherty, Hesselink, & Bellugi, 1992). An anomalous corpus callosum may contribute to the verbal-motor production problems that participants with Down syndrome often encounter when they are required to produce speech following a verbal instruction (Bunn et al, 2002). This is consistent with Elliott et al's (1987) model that proposes that, during a task requiring both speech perception and production, most individuals with Down syndrome perceive speech using their right hemisphere. After speech perception takes place, the information is transferred across the corpus callosum to the left hemisphere for production. Elliott et al. (1987) suggests that during this interhemispheric transfer information is degraded. This loss or degradation of speech information may, in turn, result in difficulty with verbal-motor production.

Many functional neuroimaging studies (e.g. Positron Emission Tomography (PET), Electroencephaolography (EEG), Evoked and Event-Related Potentials (ERP), and most recently, Magnetoencephalography (MEG)) also lend their support for Elliott's model of atypical cerebral specialization in Down syndrome. For example many PET studies have found a lower activation of the left hemisphere and higher activation of the right hemisphere during speech perception in individuals with Down syndrome (Gaetz et al., submitted).

In the last few years, researchers studying cerebral specialization for speech in individuals with Down syndrome have started using MEG. This new functional imaging technique has become popular for a variety of reasons: 1.) MEG is non-invasive 2.) Unlike MRI or fMRI, participants do not have to lie still in a confined space 3.) The time resolution for MEG, in milliseconds, is superior to many other methods. MEG uses SQUIDS (superconductive quantum interference device) to measure the magnetic fields that surround layers of cells arranged in parallel to the brain's surface (Gaetz et al., submitted). Participants are seated in a chair and a large tube-like structure containing SQUIDS rests over the top of their heads. This enables researchers to design protocols that require participants to listen and respond verbally or motorically to visual or verbal instructions. The first study to examine cerebral specialization for speech perception utilizing MEG was a case study involving one female participant with Down syndrome. The results from the study suggest that, consistent with the model, there is more activation in the right hemisphere during speech perception and greater activation in the left hemisphere during movement execution (Weeks, Chua, Weinberg, Elliott, & Cheyne, 2002).

Another functional neuroimaging technique, functional magnetic resonance imaging (fMRI), has been widely used to examine brain function. fMRI images the amount of oxygen carried by hemoglobin in the blood contained in the brain. fMRI is preferred by many researchers because of its spatial accuracy. Researchers are looking at fMRI to play an important role in research on cerebral specialization in Down syndrome. To date there have been few studies that have examined cerebral specialization for speech in this population.

Histological and cellular evidence also suggests that speech and language may be processed differently in these individuals. For example, the Superior Temporal Gyrus frequently appears straight and thin in persons with trisomy 21 (Golden & Hymen, 1994).

The brains of many individuals with Down syndrome are different both structurally and functionally. Several different neuroimaging techniques have been employed by researchers to examine these differences. This section highlighted the differences that were most relevant to speech and language processing. To summarize, the decreased volume of the Superior Temporal Gyrus and/or Planum Temporale, the anomalous appearance of the Superior Temporal Gyrus and the corpus callosum as well as the activation of the right hemisphere during speech perception may all significantly impact the way speech is perceived and processed in individuals with Down syndrome.

Dichotic Listening

Dichotic listening is a technique used by many researchers to examine cerebral specialization for speech perception. There are many advantages to using this technique to examine laterality in both children and adults. It is inexpensive, non-invasive and easy to administer. Because the majority of information presented to the right ear is projected to the left hemisphere to be processed, and most of the information presented to the left ear is projected to the right hemisphere to be processed, researchers are able to infer, using a dichotic listening technique, which hemisphere is specialized for speech perception. Dichotic listening was first used to study cerebral dominance in individuals who had endured strokes or brain injury. For example, in the 1960's, Kimura (1967) used dichotic listening to investigate functional asymmetries between the two hemispheres of the brain in individuals with right and left hemisphere brain damage. In Kimura's protocol digits were presented simultaneously to both ears. Participants with lesions in the left temporal lobe correctly reported fewer digits than participants with right temporal lesions. Kimura (1967) concluded that, in the general population, speech was lateralized to the left hemisphere and damage to this hemisphere consequently impaired speech functions. Since then several other researchers have used dichotic listening to examine cerebral dominance for speech in children who are bilingual (Obrzut, Conrad, Bryden, & Boliek, 1988), as well as children with reading difficulties (Bakker & Kappers, 1988) and learning disabilities (Obrzut et al., 1988).

In the 1980's, Hartley (1981, 1982a, 1982b, 1985) and Pipe (1983) used dichotic listening to investigate cerebral dominance for speech in children with Down syndrome. Some children who participated in the studies were as young as 3 years old. The dichotic protocols employed in these studies involved digits or word pairs presented simultaneously to both ears. Participants were either asked to recall the stimuli in any order or they were asked to selectively attend to one ear or the other. Both Pipe and Hartley found a reversed specialization for speech perception in children with Down syndrome when children were tested using a free recall procedure. Zekulin-Hartley

(1982) did not find an ear advantage for any of the three groups (participants with Down syndrome, participants with an undifferentiated intellectual disability, participants without intellectual disability of the same mental age) when they tested participants using a selective attention dichotic listening protocol. The author suggested that none of the groups displayed an ear advantage because they all had difficulty attending to their non-dominant ear. It was thought that this difficulty was related to their cognitive rather than physiological developmental stage because participants with an intellectual disability were chronologically older than participants without an intellectual disability.

In the 1990's, Elliott, Weeks, and Chua (1994) completed a meta-analysis of all published studies of dichotic listening involving persons with Down syndrome. The results of the meta-analysis suggested that individuals with Down syndrome have a left ear-right hemisphere specialization for speech perception (cf. Parlow, Kinsbourne, & Tannock, 1996; Tannock, Kershner, & Oliver, 1984) compared to individuals without Down syndrome who have a right ear-left hemisphere for speech perception.

Recent studies conducted in our lab that have further investigated the effect of visual versus verbal instruction on movement suggest that task demands may influence how laterality is manifested (Bunn, Welsh, Simon, Howarth, & Elliott, in press; Welsh, Elliott & Simon, in press). For example, Welsh et al. (in press) found that participants with Down syndrome displayed a left ear advantage for speech perception during a traditional free recall dichotic listening test which required a verbal response while the same participants displayed a right ear advantage for speech perception during a selective attention dichotic listening test which required participants to respond by pointing. A follow up study found using the same stimuli as the traditional free recall dichotic listening test used in Welsh's study (animal names) and a similar response mode to the selective attention dichotic listening test also used in Welsh's study (pointing) found no difference between the groups for ear advantage (Bunn et al, in press). The authors suggested that preparing for a manual response might prime the left hemisphere and precipitate a shift in hemispheric activation and therefore, ear advantage for speech perception. Interestingly, Bunn et al. found a significant relationship between laterality index (derived from the selective attention dichotic protocol which required participants to respond by pointing) and speech production error when participants were required to read or repeat words out loud. Therefore, while the mean laterality indices of the two groups were not significantly different, participants with more negative laterality indices had greater difficulty when they were required to repeat or read words rather than formulate words from a picture. Results from these studies suggest that we should begin investigating the individual differences in ear advantage between participants with Down syndrome rather than continuing to examine group differences.

Dichotic Listening, Gender Differences and the Development of Cerebral Dominance

Kimura (1963) also investigated the development of cerebral dominance for speech in young children and found that children can be left hemisphere specialized for speech as early as four years of age. Interestingly, while Kimura did not find a sex difference for the development of a left hemisphere specialization for speech in the sample of children who participated in an earlier study, later findings by the same author (Kimura, 1967) have suggested that young boys may be slower to develop cerebral dominance for speech. Kimura (1967) suggested that children included in the first study may have been at a later stage of development than children who participated in the later study although factors such as socio-economic status, verbal ability and intelligence could also have been responsible for the differences in the two groups of children. Unfortunately, these data were not collected. More recent work combining a selective attention dichotic listening task and a rapid aiming task found that women were less lateralized than men. The authors attributed this difference to strategic differences in task approach rather than a difference in cerebral laterality (Welsh & Elliott, 2001). While no gender differences have been reported in the literature involving cerebral specialization in individuals with Down syndrome, one might expect to find gender differences in children who were developmentally younger than those who participated in the study by Kimura (1963). In fact, research involving children who were developmentally younger than those involved in Kimura's study suggests that gender does not mediate ear advantage (Zekulin-Hartley, 1981, 1982). At this point, it seems unclear whether or not gender plays a role in cerebral specialization for speech perception.

Speech and Music Therapy for Children with Down syndrome

Up until now, there has not been any research that has examined the role of speech-language therapy and music therapy within the framework of this biological dissociation model. This research will be the first to attempt to bridge the gap between research in speech-language pathology, music therapy and research in psychomotor behaviour.

Both clinical and neuropsychological evidence suggests that the global aspects of music (pitch, melody, and timbre) may be primarily processed by the right-hemisphere (Brancucci & San Martini, 1999; McKinnon & Schellenberg, 1997), while the left hemisphere may be more specialized to process the temporal aspects (rhythm, timing, and duration) (Bradshaw & Rogers, 1993). For example, Kimura (1964) administered two dichotic listening tests to a group of nurses. The first dichotic listening test consisted of the simultaneous presentation of spoken digits while the second test consisted of the simultaneous presentation of melodies. The melodies were 4-sec excerpts of concertos played mainly by woodwind instruments. Melodies presented to the left ear were more accurately recognized than those presented to the right ear suggesting that the right hemisphere is more specialized for the perception of melodies. However, digits presented to the right ear were more accurately reported than those presented to the left ear suggesting that the left hemisphere is more specialized for the perception of speech or temporal information.

There is anecdotal evidence from speech-language pathologists, music therapists, teachers and parents that music therapy may help remediate the verbal-motor difficulties experienced by children with Down syndrome. This anecdotal evidence is consistent with research that suggests that melodic intonation therapy, a form of language therapy, helps to improve some aspects of language in individuals with left hemisphere damage (Sparks, Helm, & Albert, 1974). It may be that music therapy and music-based speech instruction facilitate interactions between the two cerebral hemispheres that would not normally occur. For example, the temporal aspects of music (rhythm, timing, duration), which depend on left hemisphere processing, may help mediate verbal-motor behaviour. The present study was the first to examine the relationship between these types of therapies and ear advantage for speech perception in individuals with Down syndrome.

Roy and Black's Apraxia Model

A short form of Roy and Black's Apraxia Battery was administered in the current study to help quantify movement errors and investigate how mode of instruction (i.e., verbal or demonstration) impacts praxis. Roy and Black's Apraxia model suggests that 3 different systems are responsible for movement production (including both oral and limb movements). The sensory/perceptual system is involved in the analysis of input information. The conceptual system provides us with the knowledge base for acting on the world. It specifically involves two types of knowledge: 1) knowledge about what to do with tools and the objects associated with them and 2.) knowledge about how to properly use tools as well as knowledge about how to make representational gestures not associated with tool use. The third system is called the production system. It is involved in the organization and control of movement. Disruptions or problems with any of these three systems will result in specific impairments. For example, a disruption in the sensory/perceptual system may cause a person to have difficulty visually recognizing a tool (e.g., comb) or gesture (e.g., eating with a fork). Disruption to the conceptual system, which involves representational gestures, will affect knowledge associated with the use of tools (transitive gestures) or gestures that do not involve the use of tools (intransitive gestures). For example, a person experiencing problems with this system may select the wrong tool for an action (e.g., a fork to comb his/her hair), although he/she will perform the action correctly. A person with a disruption to the knowledge of action part of the conceptual system may have difficulty recognizing a gesture or whether he/she is performing the movement correctly. There are four different parts of the production system that may be disrupted in a person with apraxia: response selection, image generation, working memory or the spatial and temporal organization of movement. If a person is asked to perform a movement to verbal command (pantomime), the movement needs to be generated from memory and therefore, places stress on all four parts of the production system. If a person is asked to imitate the same movement, they are required to compare the features of the movement demonstrated with that of their own and there are no demands placed on their working memory. If the researcher or clinician is continuously demonstrating the movement during the participant's imitation (concurrent imitation) then demands are only placed on response programming and control. However, if the researcher or clinician stops demonstrating before the participant is asked to imitate the movement (delayed imitation), then demands are placed on memory as well.

Because testing sessions needed to be tailored to suit the attention span of the participants that were tested, only a short form of Roy and Black's Apraxia Battery was administered. Therefore, all delayed imitation conditions were omitted from the battery. The sections of the test battery that were administered for the current study were as follows, Tool Identification, Tool Use, Action Identification, Gesture Recognition[1], Imitation-Concurrent for Transitive Representational Gestures, Imitation-Concurrent for

Transitive Representational Gestures (with verbal cue), Imitation-Concurrent for Intransitive Representational Gestures, Imitation Concurrent for Intransitive Non-Representational Gestures, Imitation Concurrent for Intransitive-Representational Oral Gestures, Oral Pantomime, Object Use, Pantomime by Tool. There were 4 tools that were used in the sections of the battery involving tools. These tools included a hammer, a comb, a fork and a toothbrush. This differed from the original battery that used 8 tools for each section involving tool use. The other 4 tools were eliminated from the short form of the battery to decrease administration time and because these tools were not appropriate for the younger children involved in the study. The Imitation-Concurrent for Intransitive Representational Gestures section involved 4 gestures, instead of the original 8, that were expected to be recognizable by most children (hold nose, wave, ear, thumbs up). The Imitation Concurrent for Intransitive-Representational Oral Gestures and the Oral Pantomime sections were also shortened to contain only 4 gestures (smile, lick lips, kiss, stick out tongue). The Imitation-Concurrent for Intransitive Non-Representational Gestures included non-meaningful limb movements that participants had never seen before. For the tool identification section, participants were required to identify each of the 4 tools used in the battery from pictures. Participants were asked to select each of the 4 tools (hammer, comb, toothbrush, fork) from an array of four tools in the tool use section of the battery. Each of the 3 distractor tools were similar to the target semantically, in function, or appearance. During the action identification and gesture recognition sections participants were required to identify when a person on a video was performing a specified action (e.g., hammering) from a set of four clips and when the person on the video was performing the same gesture as the researcher from another set of four clips. The results of this study are discussed with reference to Roy and Black's Apraxia Model, as well as Elliott's model of cerebral specialization.

Similar to Elliott and Week's (1993) study described earlier, the present study employed a dichotic listening task to examine cerebral dominance for speech in children with Down syndrome. More importantly, it examined whether or not the laterality indices derived from the dichotic listening test were related to performance on the apraxia battery and information collected in the speech-language pathology questionnaire.

The present study tested the following hypotheses: 1.) The majority of children with Down syndrome will exhibit a LEA for speech perception. 2.) Children who are right hemisphere specialized for speech perception, as determined by performance on a dichotic listening test, will score lower than children who are left hemisphere specialized for speech perception on subtests of the apraxia battery that require movement following a verbal cue than subtests that require imitation. 3.) Children who have received speech and/or music therapy will perform better on the oral praxis section of the apraxia battery as well as sections of the apraxia battery that require verbal instruction than other participants with Down syndrome who have not received therapy.

Method

Participants

Participants were 12 children and adolescents with Down syndrome age 8-15 years and 12 children without Down syndrome age 2-10 years. Participants with Down syndrome were chronologically older than control participants as we tried to obtain control participants who had similar receptive language ability. It was imperative that both groups of participants had a similar level of comprehension for instructions. Inclusion criteria for participation in the study were as follows: no known hearing loss or recent otitis media, normal or corrected-to-normal vision, absence of neurological lesion or anomaly. All participants were recruited from the Hamilton Down Syndrome Association, Express Yourself Speech-Language and Communication Service (Burlington), and the Down Syndrome Research Foundation (Burnaby).

Apparatus and Material

An audiometer was used to deliver pure tones to participants through Telephonics headphones. To ensure proper fit of the headphones during audiometry, a pediatric headset was attached to the headphones. For the dichotic protocol, a Pentium laptop computer with a sound blaster and Optimus Nova-36 headphones were used to deliver words simultaneously to both ears of the participants. A toy hammer, a fork, a comb and a toothbrush were used to administer the "Object Use" section of Roy and Black's (1998) apraxia battery. Laminated, 8 x 11.5 photo paper was used to display the pictures used in the "Object Identification" section of the battery. A Panasonic PV-DV400-K digital video camera, positioned approximately 2 metres in front of each participant, was used to film participants during the administration of the apraxia battery. A ball, a spoon and a pencil were used to determine handedness.

Procedure

If a participant had completed pure tone audiometry in the last 4 months and his/her parent or guardian did not report any recent reason for hearing loss, the researcher obtained information on hearing from the participant's audiologist. If it had been greater than 4 months since a participant had completed a pure tone audiometry test then the researcher used an audiometer to screen the participants for hearing loss. Participants that were included in the study had a hearing threshold of no more than 30 dB in both ears and no more than a 10 dB difference between their ears.

The Peabody Picture Vocabulary Test (PPVT) was administered to assess the receptive language of each of the participants with Down syndrome[2]. A performance test utilizing items from Bryden's Handedness Questionnaire (Bryden, 1977) was administered to determine handedness. Participants were asked to show the experimenter how they would write their name, eat soup and throw a ball with a pencil, a spoon and a ball. Next, a parent or guardian of each participant with Down syndrome completed a questionnaire outlining the amount and type of speech therapy received (see Appendix A).

A short form of Roy and Black's (1998) apraxia battery was administered to participants by the primary investigator to quantify movement errors. Apraxia battery administration was videotaped so researchers could score participant performance at a later date. An error notation system, similar to that used in Roy's apraxia battery, was used by three researchers. Together, all three researchers watched the videotape of the same participant to establish consistency with the error notation system. Next, the three researchers watched a participant independently and a percentage agreement was calculated for performance. The percentage agreement was calculated across dimension (Location, Posture, Action, Plane, Orientation, Extra Movement), hand (right or left), and gesture. A score was tabulated for each section and divided by the number of gestures scored in a specific section. One point was given if both researchers awarded the participant with the same score (perfect agreement), a half a point was given if the researchers disagreed by 1 (e.g., one researcher gave the participant a 2 and the other researcher gave the participant a 1) and zero points were given if researchers disagreed by 2 (e.g., one researcher gave the participant a 0 and the other researcher gave the participant a 2). Agreement between the first researcher and the primary investigator ranged from 72.8% (Imitation-Concurrent for Intransitive Non-Representational Gestures) to 95% (Imitation Concurrent for Intransitive Representational Gestures) while agreement between the second researcher and the primary investigator ranged from 77.1% (Pantomime) to 87% (Imitation-Concurrent for Intransitive Non-Representational

Gestures). Overall, the agreement between the primary investigator and the first researcher was 83% while the agreement between the primary investigator and the second researcher was 82.6%. The percentage agreement between the two researchers who were blind to the hypothesis of the study was 83.6%. The two researchers, who were blind to the hypothesis of the study, each scored half of the remaining participants. These researchers scored an equal number of participants with and without Down syndrome. The primary investigator, who was not naïve to the hypothesis, scored all the participants. The score on each section of the apraxia battery that was used in the analysis was determined by averaging the scores from the primary investigator and the other scorer.

A free-recall, dichotic listening task was also completed by participants with Down syndrome[3]. Sound files containing one-word pairs of single-syllable animal names (e.g., dog, cat, goat, goose) spoken by a male voice were prepared using two computer programs: Wave Studio and Cool Edit. Words were paired together if they were approximately the same length. The beginning of each word-pair was aligned to be within 1 millisecond of each other. There were 16 pairs of animal names presented and 64 trials. Halfway through the dichotic listening task the headphones were reversed to ensure that the connection to either headphone was not responsible for any resulting ear advantage. Presentation of word pairs was randomized for each participant. All participants were asked to listen carefully to the headphones and report as many words as they could remember. Because a free recall dichotic protocol was employed in this task, the participants were not asked to report the words in any particular order[4]. The researcher reminded participants throughout the task "to do the best you can" and that "everyone makes mistakes". Words of encouragement such as "Good Job", "Way to go", and "Excellent Listening" were used to keep participants on task. Testing took place on two separate days.

Results

To begin, group performance on the dichotic listening test was explored. Laterality indices were calculated for all participants. The formula used to calculate a laterality index was,

$$\frac{\text{Right Ear-Left Ear}}{\text{Right Ear+Left Ear}} \times 100$$

Two t-tests revealed that, although the mean Laterality Indices for the number of words correct ($M = -1.64$, $SD = 13.90$) and the order of word report ($M = -1.76$; $SD = 16.48$) for participants with Down syndrome were both negative, they were not significantly different from zero, $t(11) = -.12$, $p > .25$; $t(11)=-.11$, $p > .25$. The mean receptive language abilities of the two groups were not significantly different from one another, $t(22) = -.69$, $p > .25$. Mean receptive language ability for both groups as well as other participant characteristics can be referenced in Table 1.

Apraxia Battery

The apraxia battery was comprised of 8 different subtests that measured different aspects of movement behaviour. Scores for each subtest were calculated as a percentage of maximum performance as the maximum score a participant could receive sometimes differed with subtest. To protect alpha, a multivariate analysis was conducted where the scores on each subtest served as the dependent variables. This analysis revealed a main effect for group, Wilks' Lambda (8, 15) = .32, $p < .01$. To determine which subtests exhibited group differences, a 2 Group by 8 Section ANOVA was conducted on the individual subtest scores. The analysis revealed that there was a significant group x section interaction, $F(7, 154) = 2.49$, $p < .0190$ (Figure 1). A Tukey's HSD ($p < .05$) post hoc test demonstrated that participants with Down syndrome made more errors than participants in the control group in the Pantomine condition of the apraxia battery. They also had more difficulty than participants of similar receptive language ability in the Oral Pantomine condition. Interestingly, control participants performed more poorly than the chronologically older participants with Down syndrome in the Imitation-Concurrent for Intransitive Representational Gestures section of the battery.

To take a closer look at the type of errors participants were making in the Pantomime, Oral Pantomime and Imitation-Concurrent for Intransitive Representational Gestures sections 3 more ANOVA's were conducted. First, a 2 Group by 6 Error Type (Location, Posture, Action, Plane, Orientation, Extra-Movement) ANOVA was conducted using score on the Pantomime section of the apraxia battery. The analysis revealed a main effect for Group, $F(1,22) = 10.27$, $p < .01$, and Error Type, $F(5,110) =$

11.96, $p < .01$, but no Group x Error Type interaction, $F(5,110) = 1.26$, $p = .29$. Thus, participants with Down syndrome were making more errors than control participants, regardless of error type.

Next, a 2 Group by 2 Error Type (Oral-Verbal, Oral Verbal on Extra Movement Section) ANOVA was conducted with the score on the Oral Pantomime section of the apraxia battery as the dependent variable. The analysis revealed only a main effect for Group, $F(1,22) = 8.83$, $p < .01$. Once again, participants with Down syndrome performed more poorly than their peers regardless of error type.

Lastly, a 2 Group by 6 Error Type (Location, Posture, Action, Plane, Orientation, Extra-Movement) ANOVA was conducted using score on the Imitation-Concurrent for Intransitive Representational Gestures section of the apraxia battery as the dependent variable. This analysis revealed a Group x Error Type interaction, $F(5, 110) = 2.47$, $p < .05$. Post hoc analysis showed that participants with Down syndrome made significantly fewer errors than participants in the control group when assessed for plane of movement but made significantly more extra-movements (e.g. co-committed movements) than participants in the control group during the Imitation-Concurrent for Intransitive Representational Gestures section of the battery.

A correlational analysis revealed that chronological age was positively related to both performances on the Imitation-Concurrent for Transitive Representational Gestures, $r = .69$, $p < .05$, and the Imitation-Concurrent for Transitive Representational Gestures (with verbal cue), $r = .73$, $p < .05$, sections of the battery. Very interestingly, the analysis also revealed a significant positive relationship between performance in the Pantomine condition of the battery and both the Laterality Indices calculated using the number of words correct, $r = .59$, $p < .05$ (Figure 2), and the Laterality Indices calculated using the order of word report, $r = .70$, $p < .05$ (Figure 3)[5]. Thus, participants with more negative laterality indices (i.e., a left ear advantage) performed more poorly in the Pantomime condition. There was also a relationship between performance in the Imitation-Concurrent for Transitive Representational Gestures (with verbal cue) and Laterality Indices calculated using the order of word report, $r = .68$, $p < .05$ (Figure 4), indicating that participants with Down syndrome who had negative laterality indices performed more poorly on the imitation section of the apraxia battery that involved a verbal component. Surprisingly, there was also a significant relationship between performance on the Imitation-Concurrent for Transitive Representational Gestures and Laterality Indices (number correct), $r = .58$, $p < .05$ (Figure 5), and Laterality Indices (order of report), $r = .70$, $p < .05$ (Figure 6). Therefore, participants with Down syndrome who had negative laterality indices also performed more poorly on the imitation section of the battery that involved tools.

Speech Therapy Questionnaire

Data collected from the Speech Therapy Questionnaire can be referenced in Table 2. All children who participated in the study had received some form of speech therapy. Using only the data from the participants with Down syndrome, a correlational analysis was conducted to determine if the results from the speech therapy questionnaire were related to laterality index and/or the score on each section of the apraxia battery[6]. A moderate positive relationship was also found for apraxia diagnosis and parental report that their child has the most difficulty with articulation, phi coefficient = .58, $p < .05$. Thus, participants diagnosed with apraxia were perceived by their parents to have articulation difficulty. Apraxia diagnosis, as reported on the speech therapy questionnaire, was related to a lower score on the Imitation Concurrent for Intransitive Non-Representational Gestures, $r_b = .68$, $p < .05$, and the Pantomine, $r_b = .61$, $p < .05$, section of the apraxia battery. Thus, participants with Down syndrome who had been diagnosed with apraxia performed more poorly on the sections of the battery where they were required to pantomime or concurrently imitate intransitive, non-meaningful gestures.

Difficulty on the Oral Pantomine, $r_b = .78$, $p < .05$, section of the battery was related to having augmented communication as the main focus of the participant's therapy while difficulty on the Pantomine, $r_b = .66$, $p < .05$, section of the apraxia battery was related to receiving augmentative communication training at some point during the course of therapy. Laterality Index (order of report) was also related to whether a participant had received training in augmented communication, $r_b = .61$, $p < .05$. Participants with more negative laterality indices tended to have received some form of augmented communication. The analysis also revealed a relationship between chronological age and whether a participant had received augmented communication training, $r_b = .80$, $p < .05$. Participants who had received augmented communication training were chronologically younger.

Handedness and Gender were also included in the correlational analysis but were not significantly related to Laterality Index or apraxia diagnosis. Gender was moderately related to whether or not a participant received music therapy, phi coefficient = .68, $p < .05$, and consultation services, phi coefficient = .84, $p < .05$. Females received both consultation services and music therapy more than males.

Discussion

Laterality for Speech Perception

One of the purposes of the study was to investigate cerebral laterality for speech perception in children with Down syndrome. Interestingly, although the mean values for both laterality indices (number correct and order of report) were negative, these values were not significantly different from zero. Contrary to the hypothesis, which suggested that the majority of children with Down syndrome would exhibit a left ear-right hemisphere specialization for speech perception, participants did not show a significant ear advantage for speech perception. This is in stark contrast to many previous studies that found a consistent left ear-right hemisphere advantage for speech perception in children and adults with Down syndrome (Elliott, Weeks & Chua, 1994). It is important to note that all of the studies that used dichotic listening to investigate ear advantage for speech perception in children with Down syndrome compared their mean laterality indices for participants with Down syndrome to mean laterality indices of a control group. One possible reason why the present research did not find a significant ear advantage for participants with Down syndrome may be because the mean laterality indices were compared to zero (no ear advantage). Another possible reason why participants with Down syndrome did not exhibit a clear left ear-right hemisphere advantage for speech perception is that all participants had engaged in some type of speech therapy from a very young age. Previous research that studied cerebral specialization for speech perception in children with Down syndrome did not report the amount of speech therapy participants had received, if any (Pipe, 1983; Hartley, 1982, 1985; Zekulin-Hartley, 1981, 1982). Conversely, half of the participants with Down syndrome involved in the present study were recruited from a speech, language and communication service. It may be the case that speech therapy, and to a greater extent early intervention speech therapy, affects ear advantage in individuals with Down syndrome.

Another possible reason why the mean laterality indices for children with Down syndrome were not significantly different from zero is that 4 of the 12 participants were not right handed. Much of the previous research on cerebral specialization in individuals with Down syndrome has only involved right handed participants since left handed individuals do not consistently organize movement the same way that persons who are right handed do (e.g., Hartley, 1981; Welsh & Elliott, 2001b; Welsh, Simon, & Elliott, in press). Therefore, the results of the present study may differ from previous studies because of differences in two main participant characteristics: handedness and/or speech therapy intervention.

Speech Therapy Questionnaire and Apraxia Diagnosis

The correlational analysis unveiled a moderate, positive relationship between apraxia diagnosis and parental report that their child has the most difficulty with articulation. Hence, participants who were perceived by their parents to have the most problems with speech associated with articulation were often diagnosed with apraxia. These results should be interpreted with caution because the information collected via the speech therapy questionnaire was done through parental report. Participants with apraxia may have difficulty with articulation or parents may be biased toward selecting articulation because of their previous knowledge about what aspects of speech are usually affected by this disorder.

Apraxia diagnosis, also as per parental report, was related to performance on the Imitation Concurrent for Intransitive Non-Representational Gestures and the Pantomine section of the apraxia battery. Thus, participants with Down syndrome who had been diagnosed with apraxia performed more poorly on the sections of the battery where they were required to pantomime or concurrently imitate intransitive, non-meaningful gestures. Roy and Black's (1998) apraxia battery outlines eight different patterns of performance, but none of the patterns quite fit the inability to pantomime or concurrently imitate intransitive, non-meaningful gestures. The pattern that closest represents the pattern displayed by participants with apraxia involved in the current study is the pattern that is described by Roy and Black as an inability to pantomime, concurrently imitate, or imitate a movement after a delay. This pattern is coupled with a preserved ability to recognize a gesture, tool or object. Unlike the pattern outlined by Roy and Black, participants with apraxia did not seem to have as much difficulty with other sections of the battery where they were required to imitate the researcher or on the oral pantomime section of the battery. It is important to note that the speech pathology questionnaire did not ask parents to specify whether their child had been diagnosed with oral or limb apraxia. The etiology of oral and limb apraxia may be quite different. Patterns of performance outlined in Roy and Black's apraxia battery are for limb apraxia only. This battery does not normally contain an oral gesture section. Another reason why the results do not fit with any of the patterns of performance outlined in Roy and Black's apraxia battery is that their battery has been largely based on individuals who have apraxia resulting from stroke or brain injury. Patterns of performance for children with Down syndrome who have been diagnosed with apraxia, may be quite different.

Additionally, movements included in the Imitation-Concurrent for Intransitive Non-Representational Gestures section of the battery had never been seen before by any of the participants. However, movements in the other sections of the battery that they were required to imitate were movements that could have been fairly well practiced and therefore, not provided individuals with this type of apraxia sufficient difficulty. For example, meaningful gestures in other sections of the battery included waving, holding your nose, scratching your ear, giving the "thumbs up" sign, hammering, brushing your teeth, eating with a fork, and combing your hair. Most of these gestures participants have the opportunity to practice everyday whereas the non-meaningful gestures had never been practiced and proved to be quite difficult for children diagnosed with apraxia. Conversely, children without apraxia seemed better able to imitate the researcher.

Augmented and Alternative Communication

Difficulty on the Oral Pantomine section of the battery was related to having augmented communication as the main focus of the participant's therapy. One way to interpret this relationship is that children who had the most oral-motor problems often had a form of augmented communication as the main focus of their speech and communication therapy. Another way to interpret this relationship is that children whose therapy focused primarily on augmented communication and not oral-motor skills did not develop this skill adequately. Of course it is not possible to infer cause or effect from this correlation therefore, one can only suggest reasons for this relationship.

There was also a relationship between children and adolescents that had problems on the Pantomine section of the apraxia battery and those who had received augmented communication training. One possible explanation for this finding is that individuals may have received some sort of augmented communication training during the course of their therapy if they had difficulties with expressive language as a result of a left ear-right hemisphere specialization for speech perception. Consistent with this notion is the finding that Laterality Index (order of report) was also related to whether a participant had received training in augmented communication. Participants with more negative laterality indices tended to have received some form of augmented communication therefore, it is plausible that problems with expressive language, stemming from a left ear-right hemisphere specialization for speech perception, necessitated an alternative form of communication.

The analysis also revealed that the younger a participant was, the more likely he/she had received augmented communication therapy. Perhaps augmented communication therapy is a more popular therapeutic technique today than it was a few years ago therefore, children who are younger receive this training when they visit a speech pathologist while children who are older have received more therapy and rely less on other methods of communication.

Gender, Consultation Services and Music Therapy

While exploring the role of gender in cerebral specialization and speech therapy was not one of the primary purposes of this study it is important to recognize that females and males do not always behave similarly. Unlike Kimura's 1967 study that suggested young boys without Down syndrome might be slower to develop cerebral dominance for speech, the analysis did not yield a significant difference for gender with respect to laterality index. The results of the correlational analysis did suggest that females received both consultation services and music therapy more than often than males. There are many different ways to interpret this finding. One possible explanation is that activities such as music and the arts are perceived by our society to be activities for girls, therefore, boys are not enrolled in them. Another possible explanation is that the expectations of young boys with Down syndrome in the classroom, where needs for consultation services are often assessed and administered, might be different than for that of young girls with Down syndrome. Educators and psychologists who determine the need for consultation services may decide that boys and girls require different areas of focus (e.g., behaviour management and life skills versus communication skills). Whether this decision is based on fact or biased towards how our society perceives and perpetuates gender stereotypes cannot be determined from our analysis and is beyond the scope of this paper.

Biological Dissociation Model and Movement Execution

Elliott and colleagues' model of atypical cerebral specialization for speech perception suggests that individuals with Down syndrome exhibit difficulty with tasks that require both speech perception and movement production, including speech movements (Elliott et al., 1987). This neuropsychological model suggests that it is the functional dissociation between the areas responsible for speech perception and the areas responsible for movement execution that is responsible for the difficulty that individuals with Down syndrome encounter when attempting these types of task. In the current study, consistent with the second hypothesis, participants with Down syndrome performed at a lower level than participants in the control group in the Pantomine condition of the apraxia battery. Participants with Down syndrome also had more difficulty than participants of similar receptive language ability in the Oral Pantomine condition. In both the Oral Pantomime and Pantomime condition instructions were given verbally rather than non-verbally. These findings from both verbal conditions conform with Elliott and colleagues biological dissociation model (1987) and an earlier study by Elliott and Weeks (1993) in which adult participants with and without Down syndrome also completed an apraxia battery which involved both oral and limb movements. Elliott and Weeks (1993) found that adults with Down syndrome performed more poorly on the apraxia battery when the movements were cued verbally rather than visually. What is interesting about the present study is that the same pattern of strengths and weaknesses for different verbal versus visual cueing conditions was found for children with Down syndrome.

Interestingly, the analysis of variance also revealed that participants with Down syndrome performed better than the chronologically younger children without Down syndrome in the Imitation-Concurrent for Intransitive Representational Gestures section of the battery. Consistent with the analysis of variance, the correlational analysis revealed that chronological age for participants with Down syndrome was also positively related to performance on the Imitation-Concurrent for Transitive Representational Gestures section of the battery. One possible explanation for this finding is that participants who were chronologically older had more opportunities to practice meaningful gestures. Unexpectedly, chronological age was also positively related to performance on the Imitation-Concurrent for Transitive Representational Gestures (with verbal cue) portion of the battery. Participants who were chronologically older may also have had more experience with the tools used in this section of the battery.

Three 2 Group by 6 Error Type (Location, Posture, Action, Plane, Orientation, Extra-Movement) ANOVA's were conducted using score on the Pantomime section, the Oral Pantomime section and the Imitation-Concurrent for Intransitive Representational Gestures sections of the apraxia battery as the dependent variables respectively. The analysis revealed that participants with Down syndrome were making more errors than participants in the control group, regardless of error type for both the Pantomime and Oral Pantomime conditions. After taking a closer look at the errors made in the Imitation-Concurrent for Intransitive Representational Gestures section of the battery however, participants in the control group made significantly more plane of movement errors but significantly less extra-movements than participants with Down syndrome. The extra-movement dimension of the apraxia battery that was administered in the present study was not included in Roy and Black's apraxia battery. After testing some of the participants the primary investigator decided to include this dimension as many of the participants seemed to make co-commitant movements or extra-movements with other parts of their bodies that were not supposed to be involved in the target movement. While this finding is quite interesting, it is unclear why participants with Down syndrome made more co-commitant movements than their peers. It is also unclear why participants in the control group made significantly more plane of movement errors.

Another main purpose of the present study was to investigate if cerebral laterality was related to performance on Roy and Black's (1998) apraxia battery. The correlational analysis revealed a significant positive relationship between performance in the Pantomine condition of the battery and both the Laterality Indices. Performance in the Imitation-Concurrent for Transitive Representational Gestures (with verbal cue) was also positively related to the Laterality Indices calculated using the order of word report. Therefore, participants with more negative laterality indices experienced more difficulty with the verbal instruction portion of the battery and on the imitation section of the apraxia battery that contained a verbal element. This finding is also consistent with Elliott and Weeks (1993) who found that adult participants with Down syndrome who had more negative laterality indices, also measured by a free recall test of dichotic listening, displayed more verbal-motor problems on an apraxia battery. Again, what is interesting about the present study is that this finding can now be extended to children with Down syndrome.

Unexpectedly, there was also a significant relationship between performance on the Imitation-Concurrent for Transitive Representational Gestures and both Laterality Indices. Hence, participants with Down syndrome who had negative laterality indices also displayed evidence of difficulty on the imitation section of the battery that involved tools. Interestingly, Bunn et al. (2002) also found that participants with Down syndrome made more speech production errors for 4-item sequence lengths than participants without undifferentiated intellectual disability when required to repeat words and formulate words from a picture. Picture recognition primarily takes place in the right hemisphere (Landsell, 1968). Elliott and colleagues model makes no predictions about picture naming or object recognition. In the present study, participants were required to imitate the researcher performing a movement with a tool. Often participants would state the name of the tool or action while they were imitating the investigator. It is interesting to note, that participants in the Bunn et al. (2002) study sometimes stated the name of the picture before they were cued to report it. It is possible that participants with Down syndrome in the present study attached verbal labels to the representational gestures or tools used in the battery. This self-cuing situation is therefore, similar to the imitation section with verbal cue. Unfortunately, like the results from the imitation with verbal cue situation suggest, this self-cuing in the Imitation-Concurrent for Transitive Representational Gestures section may have hindered their performance rather than facilitated it. Because the perception of language primarily takes place in the right hemisphere and movement organization primarily takes place in the left hemisphere, interhemispheric communication may be required. Once again this is problematic for participants with Down syndrome because of a thinner, less developed corpus callosum (Wang et al., 1992) and could result in disruptions in the movement executive.

Conclusion

While mean laterality indices of participants with Down syndrome were not significantly different from zero, it was established that children with Down syndrome show a similar magnitude of variability in ear advantage to adults with Down syndrome (Bunn et al., in press). Variability in laterality for both children and adults with Down syndrome is much larger than would to be expected in a group that is often thought to be homogeneous. One possible explanation for this is that the cerebral development of persons with Down syndrome is more vulnerable to environmental demand. The relationship between laterality index and performance on the Pantomime section of the apraxia battery confirms that individual differences play a significant role in the verbal-motor behaviour of persons with Down syndrome. Group differences in performance on sections of the apraxia battery that required participants to execute a movement following verbal cue also support this notion. While the correlational analysis yielded some interesting results, participants involved in the present study did not differ very much with respect to amount or type of speech therapy received. Participants with more variability may be needed to examine the role of speech therapy intervention more closely.

Future Research

This research is the first of its kind to investigate the significance of speech therapy and, to a small extent, music therapy within the framework of Elliott and colleagues neuropsychological model. It was suggested that participants who had received speech and/or music therapy would perform better on both the oral sections of the battery and the sections of the battery in which participants were required to perform a movement following a verbal cue. It was, in fact, the case that all participants received some kind of speech therapy. Therefore, it is still unclear how speech therapy affects speech perception and communication processing. It would be very interesting for future research to compare adults with Down syndrome who received very little speech therapy to children with Down syndrome who have received many speech therapy sessions. Presently, children with Down syndrome receive much more speech therapy than children with Down syndrome received many years ago. It would be interesting to see how the laterality indices of these two groups of participants differ.

Future research may also want to explore the role of gender in access to music therapy and consultation services. It is difficult to discuss possible explanations with any conviction when such a small sample of males and females participated in this study. Another avenue that deserves exploration is the finding that participants with Down syndrome seemed to make more extra-movements than younger participants without Down syndrome during the course of the apraxia battery.

We know that individuals with Down syndrome execute movement, including speech movements, with more ease when they are imitating it rather than performing it in response to a verbal directive. It would be interesting for future research to explore if the same is true for children with Down syndrome who have been diagnosed with apraxia. These children may have more difficulty imitating novel movements and therefore, perform equally as well or more poorly on tasks that require them to execute a movement following a verbal cue. It is time to start looking at the individual differences between children with Down syndrome, as there may be many differences in the way that children with Down syndrome learn and process information.

References

Bakker, D. J. and Kapppers, E. J. (1988). Dichotic listening and reading disability. In K. Hugdahl (Ed.), Handbook of dichotic listening: Method, theory, and research (pp.513-526). Chichester, England: John Wiley & Sons.

Bunn, L., Simon, D. A., Welsh, T. N., Watson, C. & Elliott, D. (2002). Speech production errors in adults with and without Down syndrome following verbal, written, and pictorial cues. Developmental Neuropsychology, 21, 157-172.

Bunn, L., Welsh, T. N., Simon, D. A., Howarth, K., & Elliott, D. (in press). Dichotic ear advantages in adults with Down syndrome predict speech production errors. Neuropsychology.

Bradshaw, J. & Rogers, L. (1993). Brain, language, intellect, and the evolution of the self . The evolution of lateral asymmetries, language, tool use, and intellect (pp. 201-245) San Diego, California: Academic Press, Inc.

Brancucci, A. & San Martini, P. (1999). Laterality in the perception of temporal cues of musical timbre. Neuropsychologia, 37, 1445-1451.

Bryden, M. P. (1977). Measuring handedness with questionnaires. Neuropsychologia, 15, 617-624.

Chua, R.. Weeks, D. J., & Elliott, D. (1996). A functional systems approach to understanding verbal-motor integration in individuals with Down syndrome. Down Syndrome: Research and Practice, 4, 25-36.

Elliott, D. (1985). Manual asymmetries in the performance of sequential movements by adolescents and adults with Down syndrome. American Journal of Mental Deficiency, 90, 90-97.

Elliott, D., Edwards, J. M., Weeks, D. J., Lindley, S., & Carnahan, H. (1987). Cerebral specialization in young adults with Down syndrome. American Journal on Mental Retardation, 91, 480-485.

Elliott, D. & Weeks, D. J. (1990). Cerebral specialization and the control of oral and limb movements for individuals with Down's syndrome. Journal of Motor Behaviour, 22, 6-18.

Elliott, D. & Weeks, D. J. (1993). Cerebral specialization for speech perception and movement organization in adults with Down's syndrome. Cortex, 29, 103-113.

Elliott, D., Weeks, D. J., & Chua, R. (1994). Anomalous cerebral lateralization and Down syndrome. Brain and Cognition, 26, 191-195.

Elliott, D., Weeks, D. J., & Elliott, C. L. (1987). Cerebral specialization in individuals with Down syndrome. American Journal on Mental Retardation, 92, 263-271.

Elliott, D., Weeks, D. J., & Gray, S. (1990). Manual and oral praxis in adults with Down's syndrome. Neuropsychologia, 28, 1307-1315.

Gaetz, M., Weeks, D. J., Chua, R., Weinberg, H., Welsh, T. N., & Elliott, D. (submitted). Structural and functional evidence for language dysfunction in Down syndrome: a review of neuroimaging research.

Giencke, S. & Lewandowski, L. (1989). Anomolous dominance in Down syndrome young adults. Cortex, 25, 93-102.

Golden, J. A. & Hymen, B. T. (1994). Development of the superior temporal neocortex is anomalous in Trisomy 21. Journal of Neuropathology and Experimental Neurology, 53, 513-520.

Hartley, X. Y. (1981). Lateralisation of speech stimuli in young Down's syndrome children. Cortex, 17, 241-248.

Hartley, X. Y. (1982a). Selective attention to dichotic input of retarded children. Cortex, 18, 311-316.

Hartley, X. Y. (1982b). Receptive language processing of Down's syndrome children. Journal of Mental Deficiency Research, 26, 263-269.

Hartley, X. Y. (1985). Receptive language processing and ear advantage of Down's syndrome children. Journal of Mental Deficiency Research, 29, 197-205.

Heath, M. & Elliott, D. (1999). The cerebral specialization for speech production in persons with Down syndrome. Brain and Language, 69, 193-211.

Kimura, D. (1963). Speech lateralization in young children as determined by an auditory test. Journal of Comparative and Physiological Psychology, 56, 899-902.

Kimura, D. (1964). Left-right differences in the perception of melodies. Quarterly Journal of Experimental Psychology, 16, 355-358.

Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. Cortex, 3, 163-178.

Kools, J. A., Williams, A. F., Wickers, M. J., & Caell, A. (1971). Oral and limb apraxia in mentally retarded children with deviant articulation. Cortex, 7, 387-400.

Landsell, H. (1968). Effect of extent of temporal lobe ablations on two lateralized deficits. Physiology and Behavior, 3, 271-273.

LeClair, D. A. & Elliott, D. (1995). Movement preparation and the costs and benefits associated with advance information for adults with Down syndrome. Adapted Physical Activity Quarterly, 12, 238-249.

McKinnon, M. C., & Schellenberg, E. G. (1997). A left-ear advantage for forced-choice judgements of melodic contour. Canadian Journal of Experimental Psychology, 51, 171-175.

Obrzut, J., Conrad, P., Bryden, M. P., & Boliek, C., (1988). Cued dichotic listening with right-handed, left-handed, bilingual and learning-disabled children. Neuropsychologia, 26, 119-131.

Parlow, S. E., Kinsbourne, M., & Spencer, J. (1996). Cerebral laterality in adults with severe mental retardation. Developmental Neuropsychology, 12, 299-312.

Piccirilli, M., D'Alessandro, P., Mazzi, P., Sciarma, T., & Testa, A. (1991). Cerebral organization for language in Down's syndrome patients. Cortex, 27, 41-47.

Pipe, M. (1983). Dichotic-listening performance following auditory discrimination training in Down's syndrome and developmentally retarded children. Cortex, 19, 481-491.

Roy, E. A. & Black, S. E. (1998). The Waterloo-Sunnybrook Limb Apraxia Battery. University of Waterloo, Waterloo, Ontario.

Sparks, R., Helm, N., & Albert, M. (1974). Aphasia rehabilitation resulting from melodic intonation therapy. Cortex, 10, 303-316.

Tannock, R., Kershner, J. R., & Oliver, J. (1984). Do individuals with Down's syndrome possess right hemisphere language dominance? Cortex, 20, 221-231.

Wang, P. P., Doherty, S., Hesselink, J. R., & Bellugi, U. (1992). Callosal morphology concurs with neurobehavioural and neuropsychological findings in two neurodevelopmental disorders. Archives of Neurology, 49, 407-411.

Weeks, D. J., Chua, R., Elliott, D., Weinberg, H., Cheyne, D., & Lyons, J. (1997, June). The use of magnetoencephalography (MEG) to investigate cerebral specialization in Down syndrome. Journal of Sport and Exercise Psychology, 19, S117.

Welsh, T. N. & Elliott, D. (2001a). Gender differences in a dichotic listening and movement task: Lateralization or strategy? Neuropsychologia, 39, 25-35.

Welsh, T. N. & Elliott, D. (2001b). The processing speed of visual and verbal movement information by adults with and without Down syndrome. Adapted Physical Activity Quarterly, 18, 156-167.

Welsh, T.N., Elliott, D. & Simon, D.A. (in press). Cerebral specialization and information processing strategies of adults with and without Down syndrome in a task requiring verbal-motor integration. Brain and Language.

Zekulin-Hartley, X. Y. (1981). Hemispheric asymmetry in Down's syndrome children. Canadian Journal of Behavioural Science, 13, 210-217.

Zekulin-Hartley, X. Y. (1982). Selective attention to dichotic input of retarded children. Cortex, 18, 311-316.

Author Notes

This research was co-funded by the National Down Syndrome Society and the National Institute of Child Health and Human Development (National Institute of Health Grant 1R01 HD37448-01). I would also like to acknowledge the support of Digby Elliott through the Canada Research Chair program.

Thank you to the children and parents who, not only volunteered their time, but participated both passionately and enthusiastically in this research.

Special thanks also to the staff at the Down Syndrome Research Foundation, the Hamilton Down Syndrome Association, Express Yourself Communication Services, and the McMaster Children's Centre.

Footnotes

1. Four sections of the apraxia battery (Tool Identification, Tool Use, Action Identification, Gesture Recognition) were not included in the analysis. These sections were essentially used to screen the participants to make sure they could correctly 1.) identify the tools used in the battery from a group of pictures including distractors 2.) identify, from a group of pictures, the tools used to perform specific actions 3.) identify the action associated with each tool from a demonstration 4.) recognize a gesture and select it from a sample of four demonstrations. Participants that made mistakes in the initial screening were given the correct answer and then re-tested on the next day of testing. The majority of participants did not make any mistakes on these four sections of the battery.
2. It was assumed that the receptive language of the participants without Down syndrome was equivalent to their chronological age.
3. A dichotic listening protocol was only used to test participants with Down syndrome because the results of numerous studies have shown that mean laterality indicies generated from participants with Down syndrome consistently differ from those of participants without Down syndrome (see Elliott & Weeks, 1994 for a meta analysis). Specifically, individuals without Down syndrome exhibit a right ear advantage-left hemisphere advantage for speech perception while individuals

with Down syndrome usually exhibit a left ear-right hemisphere advantage for speech perception.

4. A selective listening protocol was not used because it was thought that the instructions for a free recall protocol would be much easier for young children to understand. Past research suggests that results derived from both dichotic listening protocols are not significantly different (Giencke & Lewandowski, 1989).
5. The degree of the relationship depicted in Figure 3, 4 and 5 is largely affected by two extreme laterality scores (order of report).
6. Some sections of the questionnaire were omitted from the analysis. These sections were omitted because there was not enough variability in parental response (i.e., almost all or almost no participants answered "yes" to the question asked).

Table 1

Participant Characteristics

Group	Gender		Chronological Age (yrs)		Receptive Language Ability (yrs)		Handedness	
	Male	Female	M	SD	M	SD	Right	Left
DS	5	7	10.97	2.32	4.77	1.48	8	4
Control	5	7	5.32	2.28	5.32	2.28	9	3

Table 2

Results from Speech Pathology Questionnaire

Question Asked	Number of Participants Who Answered 'Yes' (/12)
Type of Therapy Received	
Parent Training	10
Total Communication	8
One-to-One	11
Group	6
Consultation Services	6
Other	4
Received in Therapy to date	
Oral Motor	11
Articulation	12
Expressive Language	11
Receptive Language	7
Augmentative Communication	10
Other	2
Main Focus of Therapy**	
Oral Motor	3
Articulation	10
Expressive Language	3
Receptive Language	0
Augmentative Communication	2
Other	2
Most Difficult**	
Oral Motor	1
Articulation	9
Expressive Language	6
Receptive Language	0
Augmentative Communication	0
Other	0
Other Information	
Apraxia diagnosis	6
Music Therapy	9

** Note: Parents were asked to select only one "Main focus of Therapy" and one aspect of speech that their child found "Most Difficult" but some parents selected more than one.

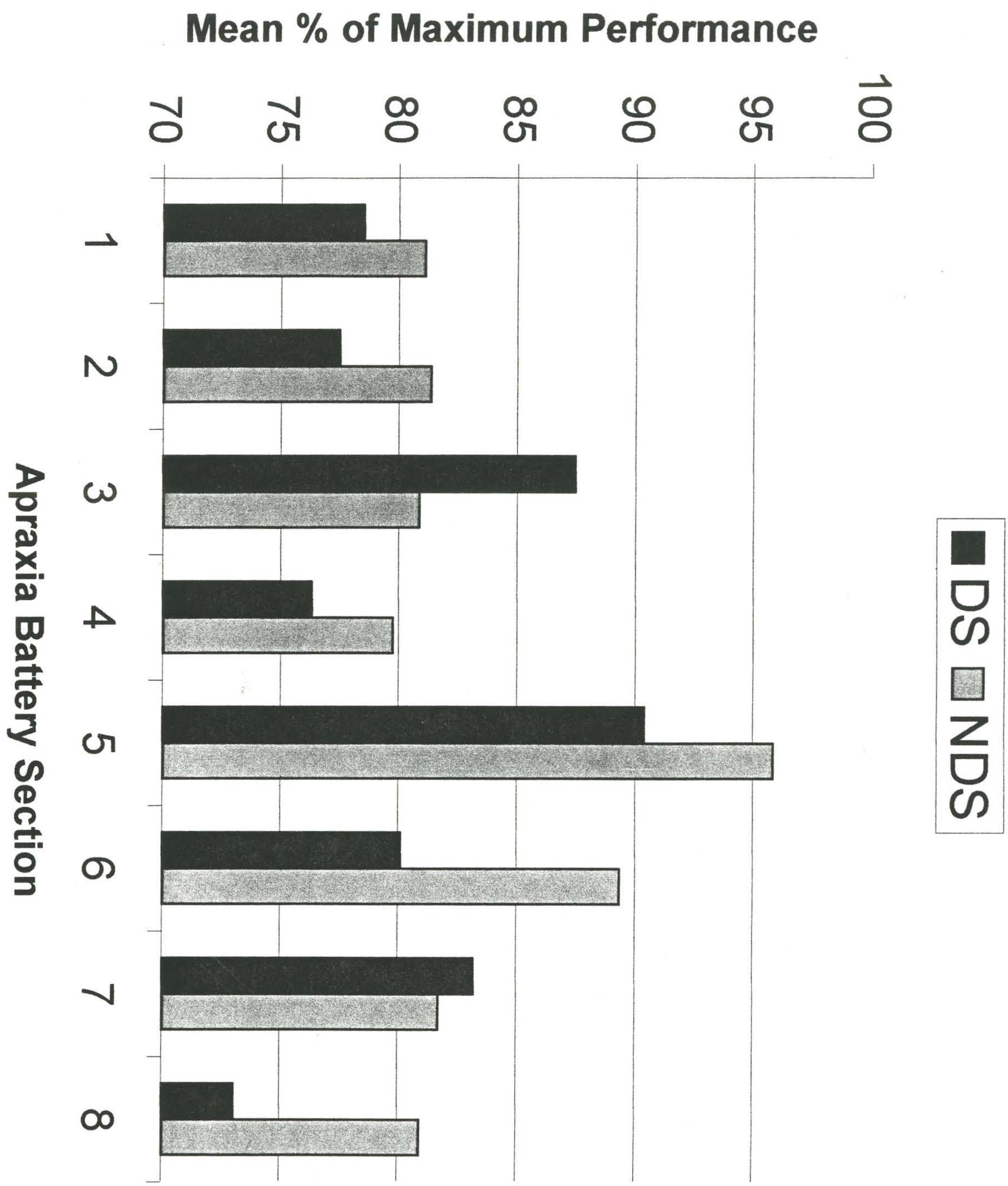
Figure Captions

Figure 1 — Mean % of Maximum Performance on Each Section of the Apraxia Battery for Participants with Down syndrome (1=Imitation-Concurrent for Transitive Representational Gestures, 2=Imitation-Concurrent for Transitive Representational Gestures (with verbal cue), 3=Imitation-Concurrent for Intransitive Representational Gestures, 4=Imitation-Concurrent for Intransitive Non-Representational Gestures, 5=Imitation-Concurrent for Intransitive-Representational Oral Gestures, 6=Oral Pantomime, 7=Object Use, 8=Pantomime by Tool)

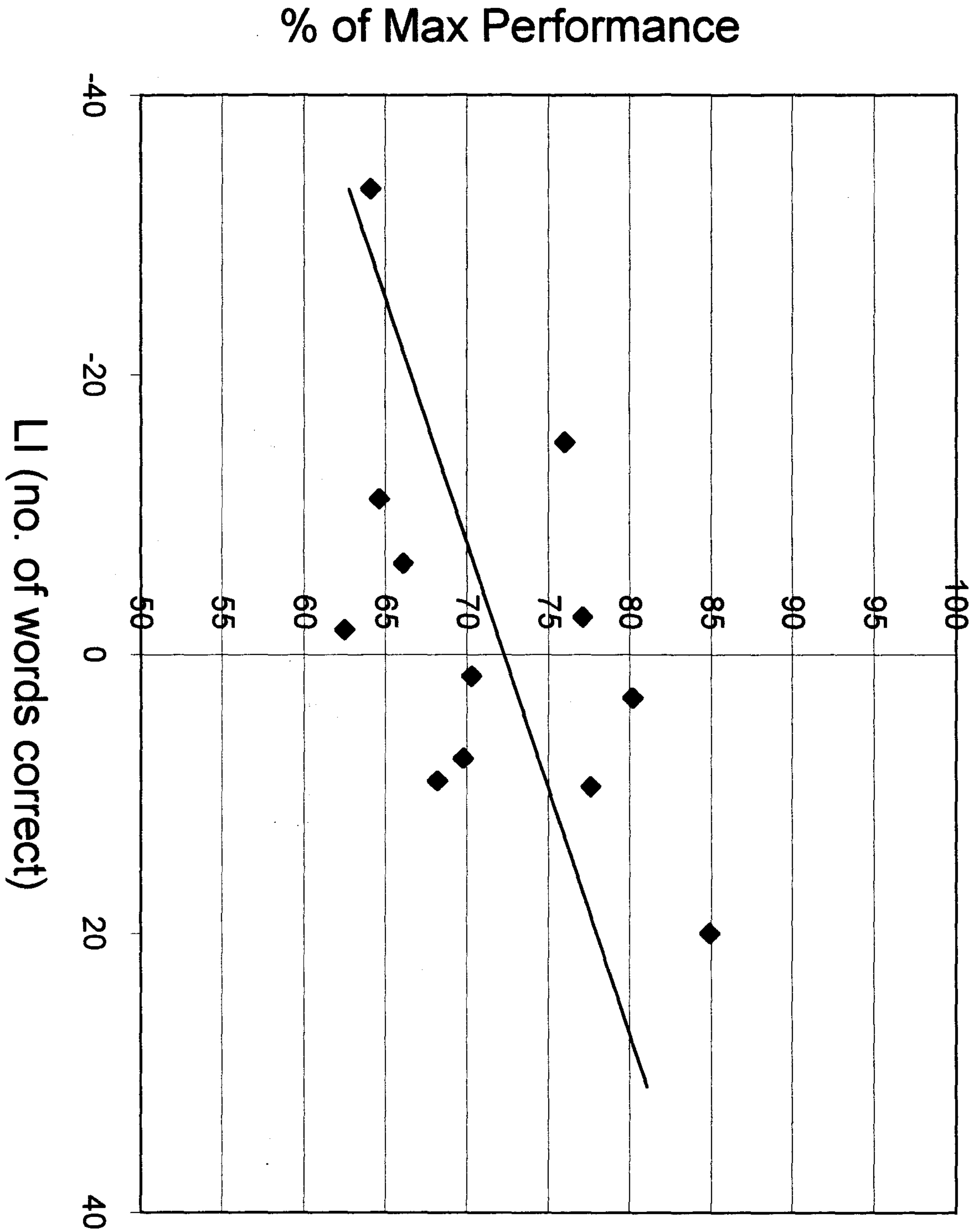
Figure 2 — Relationship between Performance on Pantomime Section and Laterality Index (number of words correct) for Participants with Down syndrome

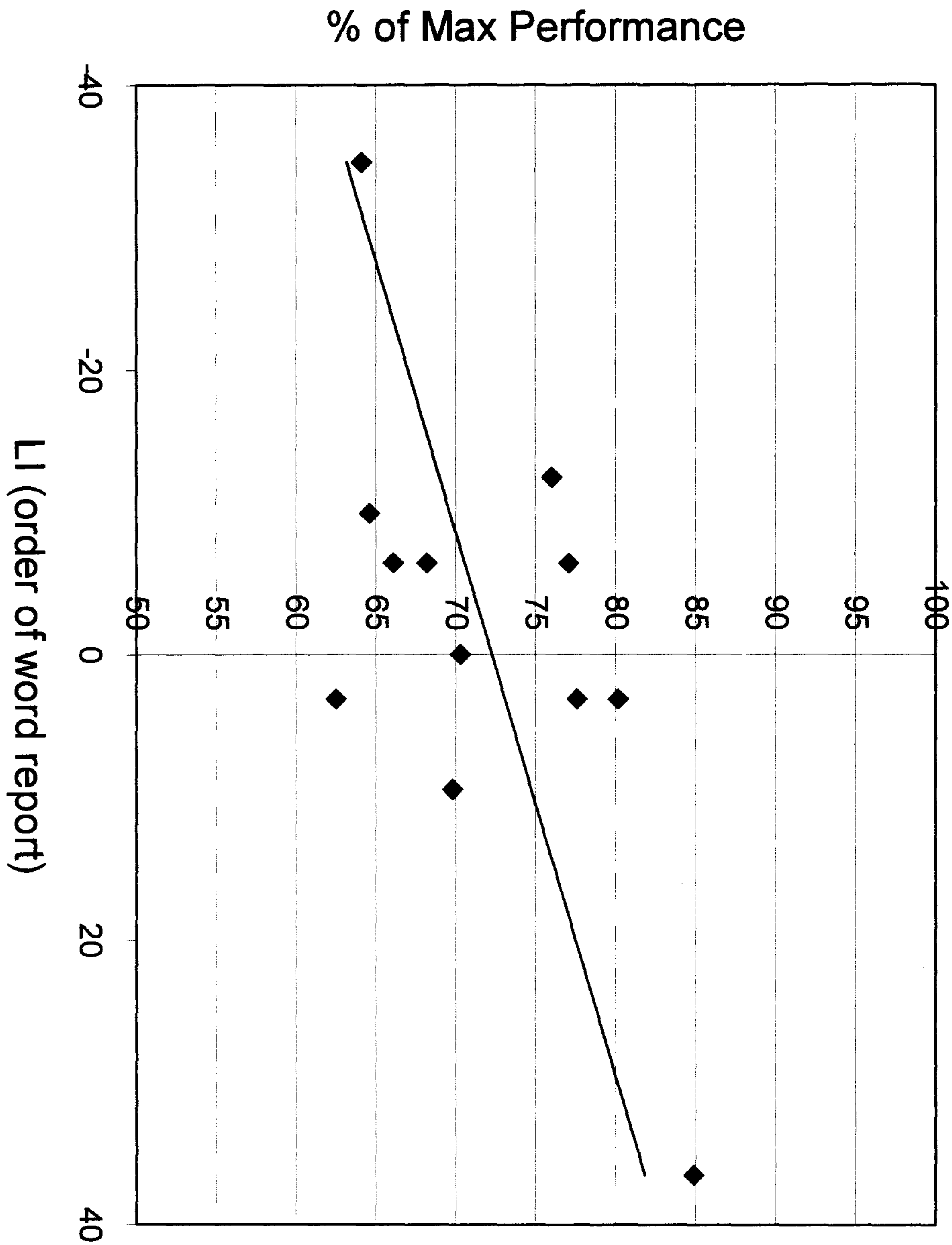
Figure 3 — Relationship between Performance on Pantomime Section and Laterality Index (order of word report) for Participants with Down syndrome

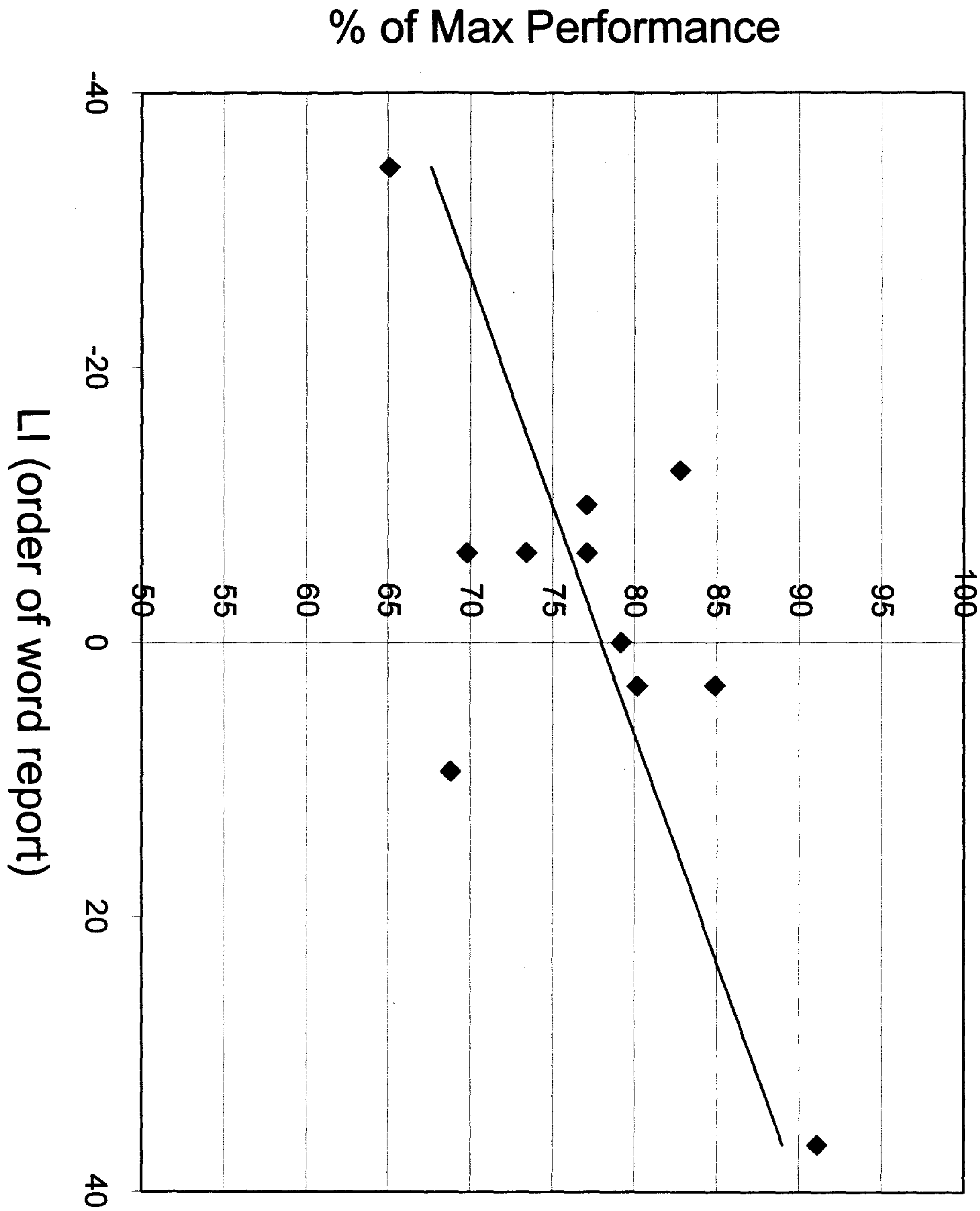
Figure 4 — Relationship between Performance on Imitation-Concurrent for Transitive Representational Gestures (with verbal cue) and Laterality Index (order of word report) for Participants with Down syndrome

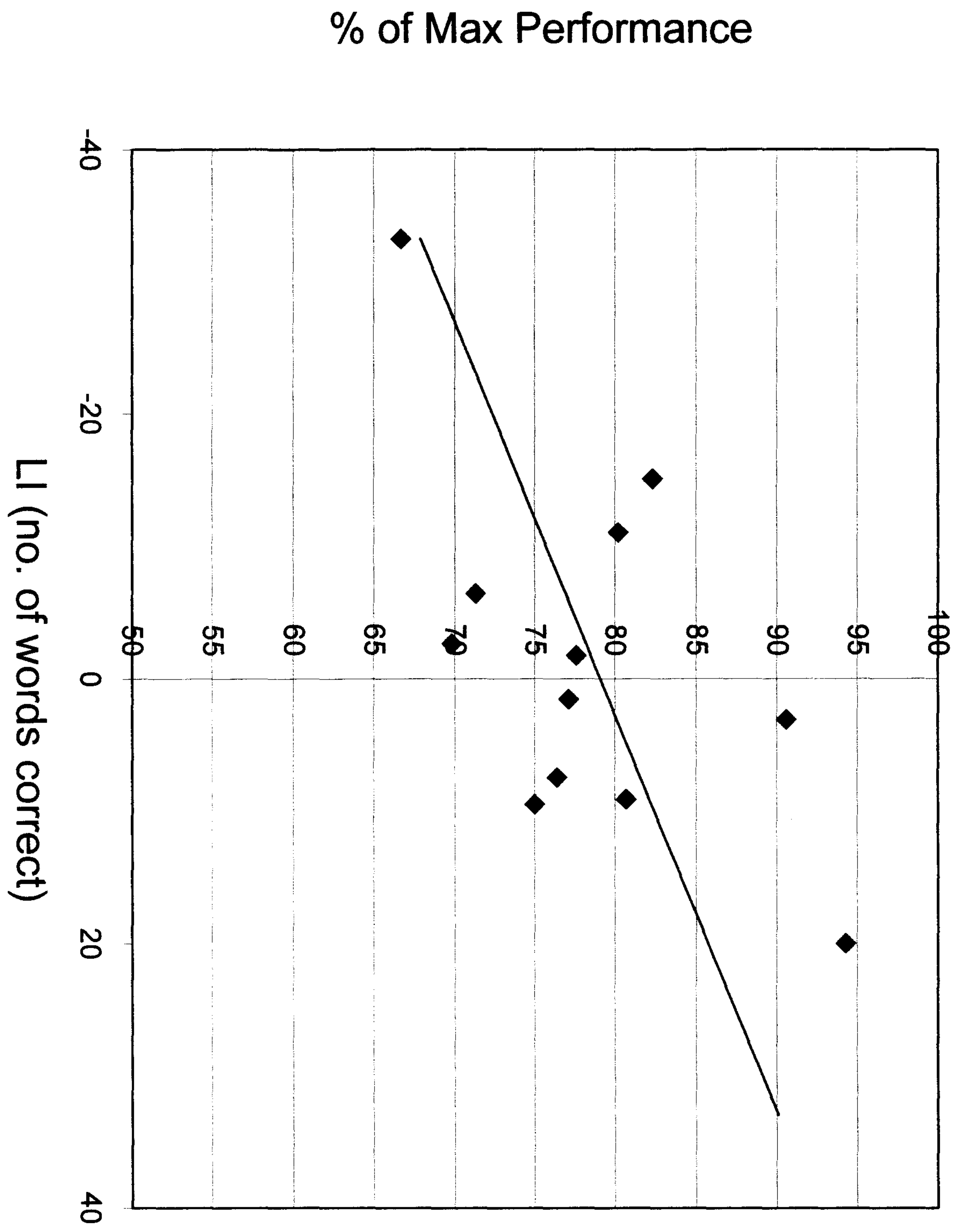


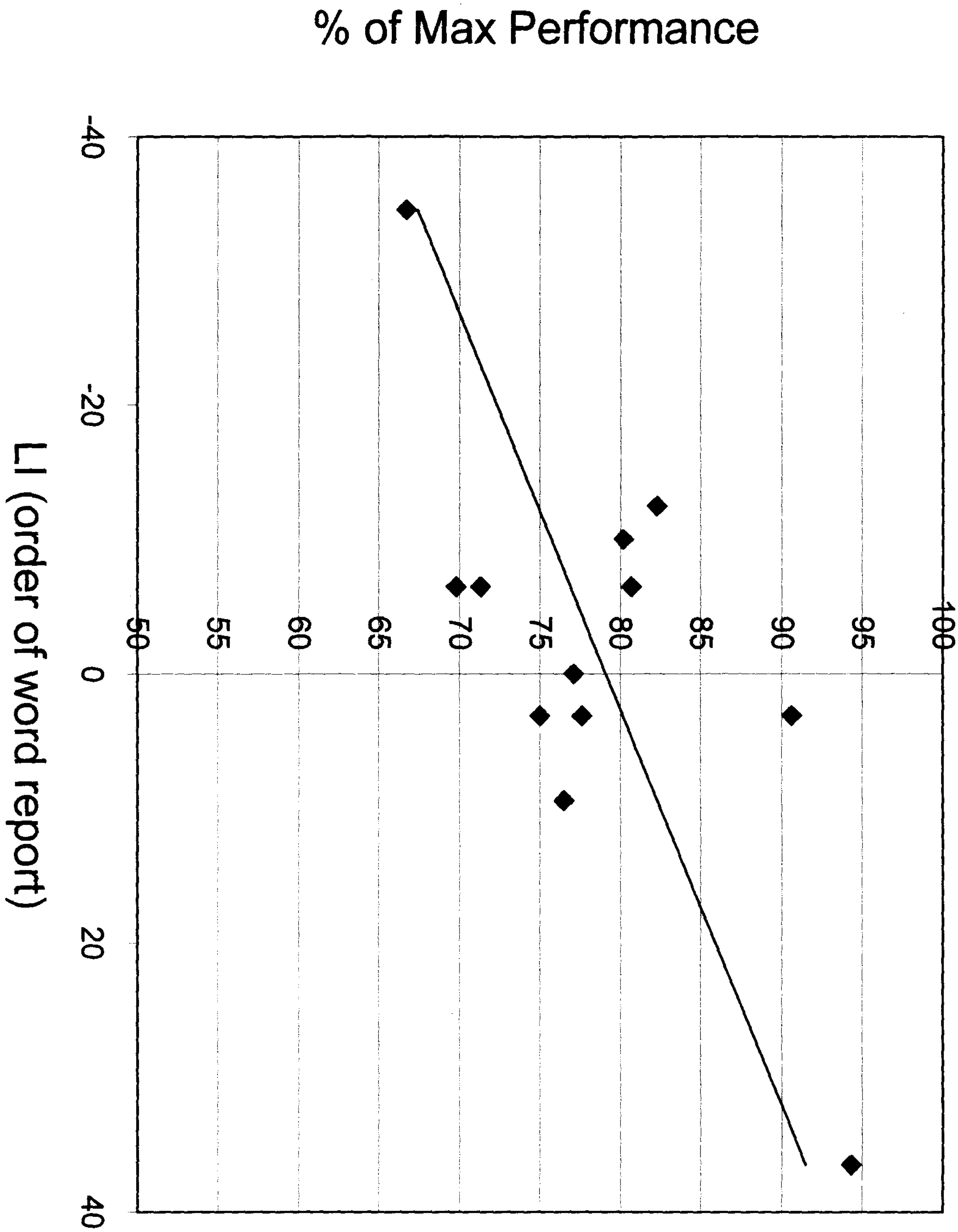
Mean % of Maximum Performance
100
95
90
85
80
75
70
1
2
3
4
5
6
7
8
Apraxia Battery Section
DS
NDS


% of Max Performance
LI (no. of words correct)
-40
-20
0
20
40
50
55
60
65
70
75
80
85
90
95
100


% of Max Performance
LI (order of word report)
-40
-20
0
20
40
50
55
60
65
70
75
80
85
90
95
100


% of Max Performance
LI (order of word report)
-40
-20
0
20
40
50
55
60
65
70
75
80
85
90
95
100


% of Max Performance
100
95
90
85
80
75
70
65
60
55
50
-40
-20
0
20
40
LI (no. of words correct)



% of Max Performance
LI (order of word report)
-40
-20
0
20
40
50
55
60
65
70
75
80
85
90
95
100

Appendix A

Speech Therapy Questionnaire

Name of Child : ________________________________ Birthdate: _____________

Name of Parent/Guardian: _________________________

Address: ______________________________________ Phone: ______________

____

____

1. Has your child ever received any speech therapy/speech language pathology/speech training? (Please circle one.)

   YES NO

2. If yes, what type(s) of speech therapy has your child received to date? (For all those that apply please indicate the age therapy began (years), frequency of sessions (hours/week), and duration of therapy (years).)

   - ❑ Parent training (age___; frequency____; duration____)
   - ❑ Total Communication (age ____; frequency ____; duration ____)
   - ❑ One-to-one speech & language therapy (age___; frequency __; duration____)
   - ❑ Small group speech & language therapy (age___; frequency__; duration____)
   - ❑ Consultation services (e.g. daycare, school) (age__;frequency__;duration__)
   - ❑ Other _______________________(age___; frequency;___;duration____)

3. What has your child worked on thus far? (Check all that apply.)

- ❑ oral motor development
  - ❑ oral motor exercises
  - ❑ other ___________
- ❑ articulation
  - ❑ speech/sound practice
  - ❑ prompt method (physical guidance)
- ❑ expressive language
- ❑ comprehension/receptive language
- ❑ augmented communication
  - ❑ sign
  - ❑ picture board
  - ❑ voice output
  - ❑ other ___________

4. What do you think has been the main focus of your child's speech therapy? (Please check one.)

- ❑ oral motor development
  - ❑ oral motor exercises
  - ❑ other ___________
- ❑ articulation
  - ❑ speech/sound practice
  - ❑ prompt method (physical guidance)
- ❑ expressive language
- ❑ comprehension/receptive language
- ❑ augmented communication
  - ❑ sign
  - ❑ picture board
  - ❑ voice output
  - ❑ other ___________
- ❑ other __________________

5. What do you think your child finds the most difficulty with now?

- ❑ oral motor development
  - ❑ oral motor exercises
  - ❑ other ___________
- ❑ articulation
  - ❑ speech/sound practice
  - ❑ prompt method (physical guidance)
  - ❑ other ____________
- ❑ expressive language
- ❑ comprehension/receptive language
- ❑ augmented communication
  - ❑ sign
  - ❑ picture board
  - ❑ voice output
  - ❑ other ______________
- ❑ other ________________

6. Has your child ever been diagnosed with any of the following? (Please check all that apply.)

- ❑ Motor speech disorder
- ❑ Apraxia
- ❑ Dysarthria

7. If you answered yes to question #6, what specific therapy has been used to address this diagnosis?

- ❑ Oral motor development
  - ❑ Oral-motor exercises
  - ❑ Other ____________
- ❑ Articulation training
  - ❑ Prompt method
  - ❑ Speech/sound practice
  - ❑ Other ____________

8. Has your child ever received music therapy? (Please circle one.)

YES NO

9. If yes, what type? (For all those that apply please indicate the age therapy began (years), frequency of sessions (hours/week), and duration of therapy (years).)

- ❑ One-to-one music therapy (age ____; frequency____; duration_____)
- ❑ Group music therapy (age _____; frequency_____; duration_____)

Appendix B

Waterloo-Sunnybrook Apraxia Battery (modified/short form)

Apraxia Battery Section	Instructions
Tool Name	Participant is asked to name the object in the picture provided.
Tool Name by Function	Participant is asked to name the tool whose function is being described by the examiner.
Tool Identification	A set of four pictures is shown to the participant. The participant is then asked to point to the tool that has been named.
Tool Identification by Function	A set of four pictures is shown to the participant. The participant is asked to point to the picture of the tool that has been described by its action.
Imitation-Concurrent for Transitive Representational Gestures	The examiner demonstrates a gesture to the participant. The participant is asked to copy the examiner right away.
Imitation-Concurrent for Transitive Representational Gestures (with verbal cue)	The examiner demonstrates a gesture to the participant. The participant is asked to copy the examiner right away. As the examiner does the gesture, he/she also indicates the gestures being imitated.
Imitation-Concurrent for Intransitive Representational Gestures	The examiner demonstrates a gesture to the participant. The participant is asked to copy the examiner right away.
Imitation-Concurrent for Intransitive Non-Representational Gestures	The examiner demonstrates a gesture to the participant. The participant is asked to copy the examiner right away.
Imitation Concurrent for Intransitive Representational Oral Gestures	The examiner demonstrates an oral gesture to the participant. The participant asked to copy the examiner right away.
Oral Pantomime	The participant is given the name of an oral gesture. Next, they are asked to demonstrate the gesture.
Object Use	The participant is give the actual object and then asked to show how they would use it.
Pantomime by Tool	The participant is told the name of the object and then asked to pretend that they are holding the object in their hand. Next, they are asked to demonstrate how they would use the tool.