CEREBRAL SPECIALIZATION FOR SPEECH AND COMPLEX ORAL VERBAL MOVEMENTS IN DOWN SYNDROME

CEREBRAL SPECIALIZATION FOR SPEECH AND COMPLEX ORAL VERBAL MOVEMENTS IN DOWN SYNDROME

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TO MY PARENTS

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WHOSE LOVE HAS MEANT SO MUCH

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Abstract

The neurobehavioural organization of speech perception and production in persons with Down syndrome (DS) is still not clearly understood. The current study investigated the cerebral specialization for speech production using a mouth asymmetry paradigm. In right handed, non-handicapped subjects the mouth asymmetry methodoogy has shown a facilitation on the right side of the mouth during expressive speech. The right mouth asymmetry is believed to reflect the dominace of the left hemisphere for speech production (Graves, Goodglass & Landis, 1982). In the present study the lateralization for the production of speech was investigated in 10 right handed participants with Down syndrome and 10 non-handicapped subjects. The results indicated that a tendency for a right mouth advantage (RMA) at the initiation and end of speech production occurred in both subject groups. Surprisingly, the degree of asymmetry did not differ, suggesting that the focal representation of speech production is lateralized similarly in both subject groups. Additionally, a high proportion of verbal errors were made by individuals with DS. These results are consistent with the model of biological dissociation (Elliott & Weeks, 1993), which asserts that individuals with DS are impaired on verbal-motor tasks due to the functional separation between speech perception centers in the right cerebral hemisphere, and speech production centers in the left cerebral hemisphere.

Introduction

Speech perception, production and abstract linguistic centers within the human cerebrum allow the expression of emotions and thought through overt motor output. This motor output represents the most complex purposeful motor action (Pinelli, 1992), explaining why research in this area has been unable to concretely identify all cerebral mechanisms responsible for speech and language. Additionally, it is unclear whether speech production is subserved by an abstract linguistic mechanism, or is an independent motor output system (Roy & Storer, 1985). The bridge between understanding the cerebral organization for speech and language is especially wide in the case of developmental disorders such as Down syndrome. The diffuse nature of morphological and chemical impairments in the DS brain resulting from trisomy 21 may obscure a definitive answer regarding the cerebral organization for these individuals. However, a more optimistic view holds that the study of atypical brain organization in persons with DS will not only lead to greater insight into the nature of their cognitive difficulties, but also, to a better understanding of neurobehavioural systems in general.

Historically, the study of language has generated considerable research interest in attempting to determine the "*seat*" of language within the human cerebrum. In 1861, Paul Broca observed that language deficits resulted from lesions to the left hemisphere, rather than to the right hemisphere (cited in

Kimura, 1993). Broca's ground breaking observation led to the establishment of a "localizationist" viewpoint, suggesting that speech and language are lateralized to the left hemisphere in the human cerebrum. These initial observations have inspired a myriad of studies, which have examined the functional capabilities of the two cerebral hemispheres for speech and language.

Clinical examinations of brain injured individuals have produced a wealth of knowledge with respect to the cerebral organization for speech production and other motor tasks. Perhaps most intriguing is the suggestion that, within the left hemisphere, speech production can be functionally separated from the lexical selection of abstract symbols required for language production (DeRenzi, Pieczuro & Vignolo, 1966). This dissociation can be clearly elucidated from the study of aphasia and apraxia of speech. Aphasic patients are characterized by their inability to appropriately select and utilize the phonological symbols associated with language. A preserved ability to select phonoloigcal structure is associated with apraxia of speech, but results in extreme variability in generating the appropriate motor response related to the phonetics of speech production (McNeil & Kent, 1990). Thus, the sensorimotor implementation of speech, is distinct from the linguistic processing required for language. Attempts to develop a theoretical model of the relationship between the two systems has proven challenging. A review of studies examining this issue have shown that aphasia and apraxia do co-occur. However, there is also evidence that they are independent (Square-Storer, Roy, & Hogg, 1990). It is likely that aphasia and apraixa often co-occur due to: the anatomical proximity between the two centers, or from a shared neural mechanism (see Kertesz, 1985, for review).

An examination of impaired linguistic processing versus impaired motor programming has been used to further dissociate aphasia from apraxia. The perception of speech in patients with apraxia of speech remains relatively intact, while the processing for aphasic patients is severely impaired (Square-Storer, Darley, & Sommers, 1988). It is evident that speech and language are distinct. The next section will review the global functions of the left hemisphere for both speech and language

Left Hemisphere Dominance for Speech and Language

Clinical investigations of brain damaged individuals have shown that in right handed individuals, left hemisphere damage (LHD) results in an increased incidence of speech and language disorders. Right hemisphere damage (RHD) has been shown not to adversely affect language to the same extent as LHD (Kimura, 1993). Disruptions to language and speech production follow the same pattern of cerebral organization in the congenitally deaf, who rely on a manual motor system for communication. Kimura (1981) has found that the ability to communicate through signing was significantly impaired following

LHD. The impaired ability to sign following LHD merits the speculation that it is not only the linguistic structure of language which is lost, but additionally involves a disruption to the motor output system required for the organization of the temporal transitions required in manual sign language (Hiscock, Bellugi, & Klima, 1996; Kimura, 1977, 1981).

Left hemisphere dominance for speech and language has been investigated by a wide variety of techniques which attempt to isolate the cerebral hemispheres. Sodium amytal when given intracarotidly depresses synaptic activation in either the left or the right hemisphere, depending on the side of injection. Wada and Rasmussen (1960) administered sodium amytal to assess the spread of epileptic discharges between the two cerebral hemispheres. Interestingly, they found that language deficits following inactivation of the left hemisphere severely impaired the ability of patients to produce intelligible speech. This was not the case following right hemisphere inactivation. Sperry and Gazzaniga (1967) have similarly been able to isolate the cerebral hemispheres through the systematic observation of patients with commissurotomies. The right hemisphere acting alone has been found unable to write or produce the propositional components of speech.

Additional support pertaining to left hemisphere dominance for language has been garnered via morphological studies of the cerebral hemispheres. In a preliminary study of 100 post mortem brains, Geschwind and Levitsky (1968) revealed that the left planum temporale was on average 0.9 cm longer than that of the RH . With the advent of high resolution neuroimaging techniques, planum temporale length is now assessable “in-vivo”. Foundas, Leonard, Gilmore, Fennel and Heilman (1994) similarly have shown that planum temporale length is greater in the left hemisphere than the right. These results suggest that planum temporale asymmetries and anatomic asymmetries play an important role for language laterality.

Non-invasive neuropsychological techniques provide a means for assessing the lateralization of functions in the cerebrum (Bryden, 1982). Visual field presentation is one such technique. Lateralization of cerebral function is determined by identifying which visual field/cerebral hemisphere exhibits an advantage for the recognition of various stimuli. When information is presented tachistoscopically to the left or right visual field, subjects are better able to recognize language stimuli that is presented to the right visual field (Kimura, 1966). The right visual field advantage occurs due to the direct contralateral projections from the retina in the right and left eye to the left hemisphere visual cortex, which enables information to be processed more efficiently by the dominant left hemisphere (Umilta, Rizzolatti, Anzola, Luppino & Porro, 1985).

Dichotic listening studies are an additional methodology for examining the cerebral specialization for speech perception. The dichotic paradigm involves the simultaneous presentation of auditory stimuli to both ears. This procedure typically results in a right ear advantage (REA) for the selective or free recall of auditory stimuli high in language content (Cutting, 1974; Kimura, 1993). The REA for language stimuli is presumed to reflect the right ear's direct access to the left hemisphere's auditory cortex. The dominance of the left hemisphere for the perception of language facilitates the transmission of stimuli along the contralateral pathway, while suppressing material being conveyed by weaker ipsilateral pathways from the left ear (Kimura, 1993). Dichotic scores are increasingly right ear biased in the case of individuals with commissurotomies. These individuals are completely unable to report stimuli presented to the left ear in the presence of competing stimuli in the right ear, thus, confirming the greater effectiveness of crossed auditory pathways projecting to the left hemisphere (Sperry & Gazzaniga, 1967).

Drawing strong conclusions concerning cerebral organization based on dichotic listening studies is extremely problematic due to the nature of the dichotic paradigm. Bryden (1982) has suggested that the magnitude and direction of an ear advantage can be influenced by factors such as stimuli type, speed of presentation and recall instructions. Order biases, attentional biases, perceptual differences, and memory trace differences may also explain the differences found in dichotic listening studies. However, support for the dichotic methodology includes a left ear advantage (LEA) for the dichotic presentation of music. This LEA reflects the right hemisphere superiority for processing musical stimuli (Kimura, 1961). The right hemisphere dominance for music has been reported in a wide number of studies employing various methodologies. The ability to process and produce music remains functional following suppression of left hemisphere activity (Bogen & Gordon, 1971; Yamodori, Osumi, Masuhara & Okubo, 1977), but is depressed following RHD (Henson, 1985). Singing without words does not result in asymmetrical facial expression, thereby implying greater right hemisphere involvement for this task (Cadalbert, Landis, Regard & Graves, 1994). Therefore, the LEA found for music supports the notion that dichotic listening studies are able to determine cerebral organization for qualitatively different sources of acoustic stimuli.

Manual Asymmetries and Complex Movements

Asymmetry in the human cerebrum is not only present for speech and language tasks, but also other motor tasks. The study of manual asymmetries has generated the largest research interest. Manual asymmetries result from contralateral hemisphere control, and are attributed to the proficiency of the two cerebral hemsipheres at various perceptual-motor tasks (Todor & Smiley, 1985). Right handed individuals typically display a right hand superiority for tasks such as rapid finger tapping and sequencing (Edwards & Elliott, 1987; Peters & Durding, 1979; Todor & Kyprie, 1980, 1982), reciprocal tapping (Todor & Doane, 1978) and manual aiming (Elliott, Roy, Goodman, Carson, Chua & Maraj, 1993). The right hand advantage is believed to result from a left hemisphere specialization for the control of more complex movements. Elliott and Chua (1996) have suggested that the right hand advantage may be due to a left hemisphere superiority for movement organization or motor programming. More specifically the mechanisms responsible for a right hand advantage, in the above tasks may include enhanced control of complex movements requiring movement transitions (Kimura, 1977, 1982) or coordinating the spatial-temporal transitions of muscular efforts (Kent & Rosenbek, 1983; Roy & Square, 1985).

Like language a great deal of our knowledge in the realm of motor asymmetries has been accumulated through the systematic observation of deficits to the manual system following damage to the left or right hemisphere. This line of research has shown that LHD subjects are bilaterally impaired on a rapid arm task, whereas a RHD group is impaired contralateral to the lesion site (Wyke, 1967, 1971). Thus, even though both hemispheres exert contralateral control of distal and proximal musculature (Todor & Kyprie, 1982), the ability of each hemisphere to control the higher order complexity of a movement is not symmetrically organized. In the case of rapid arm tasks (Wyke, 1967, 1971), the inability to perform the task may be a result of ineffective temporal phasing of flexor and extensor muscular efforts.

Kimura and Archibald (1974) noted that LHD subjects have more difficulty copying familiar and unfamiliar movements with their hands than RHD subjects when the number of sequences required to complete the movement exceeded one. However, this movement impairment is not present in simple tasks, such as single finger flexion, or copying static hand postures. Indeed, Kimura (1977) has hypothesized that it is not a spatial-temporal discoordination that results from LHD, but an inability of LHD subjects to make transitions from one posture to another. While, the spatial-temporal theory (Kent & Rosenbek, 1982; Roy & Square, 1985) and the postural transition theory (Kimura, 1977) differ with respect to the exact mechansim for controlling complex movements, it is encouraging that both theories agree that the left hemisphere is specialized for this function.

Testing the theory of left hemisphere specialization for motor tasks can be accomplished through the observation of movement impairments in individuals with apraxia. Apraxia occurs more frequently following LHD damage than RHD (Roy, 1985). It is defined as a disorder in learned or skilled movement and "is thought not to be due to a basic motor impairment, poor comprehension, dementia, nor a general decline in cognitive function" (Roy, Elliott, Dewey, & Square-Storer, 1990, p. 359). The impairments associated with apraxia are therefore related to a faulty control mechanism at the movement executive system. One view holds that apraxia is a movement selection disorder (Haaland, Porch, & Delaney, 1980; Roy, 1985). Kimura

(1977, 1982) contends that this disorder is not a failure in the proper execution of limb position, but reflects an inability to make a transition from one position to another. This inability is reflected in two simple tasks, requiring different tasks demands. A repetitive task, screwing a nut on a bolt, was not impaired for apraxic patients; however, tasks requiring movement transitions, pushing a button, pulling a handle and pressing a lever resulted in a significantly impaired performance for the apractic group (Kimura, 1977). Similar results have been found when comparing simple finger tasks to more complex motor tasks such as the production of symbolic and meaningless gestures (e.g., Haaland et al., 1980). These results suggest that the left hemisphere is dominant for demanding tasks which involve the sequencing of responses.

Apraxia is not limited to manual output systems, but also affects the oral motor system (Kimura, 1982; Lapointe & Wertz, 1974; Mateer & Kimura, 1977; Mateer, 1978; Poeck & Kerschensteiner, 1975). Impairments to manual and oral movements reflect a shared mechanism which underlies the ability of the manual and oral system to perform complex movements (DeRenzi et al., 1966; Roy & Square, 1985). Kimura (1982) has hypothesized that single oral and manual movements are controlled by two different areas of the left hemisphere. The parietal region is critical for the control of single manual movements, while the production of single oral movements is dependent on the frontal region. However, sequential manual and oral movements are critically dependent on the cooperation of both the frontal and parietal regions for accurate movement production (Kimura, 1982). Support for Kimura's (1977) theory that the left hemisphere is specialized for postural transition has been provided by Ojemann and Mateer (1979) who isolated a region in the left hemisphere responsible for sequential oral-facial movements. Electrical stimulation of this area adversely affected sequential oral-facial movements, but did not affect repeated facial movements.

In a non-handicapped population, the interference paradigm provides a method for perturbing the left hemisphere to assess the interaction of the manual and oral motor systems. The concurrent production of speech during the performance of a manual task disrupts performance of the right hand more than the left hand (Kinsbourne & Cook, 1971; Lomas & Kimura, 1976). Interestingly, speech production is also impaired, as reflected by increased error rates in target syllable production while performing a right hand tapping activity (Heath, Murdoch, Elliott & Roy, in preparation). The above findings provide additional support for a common mechanism in the left hemisphere subserving complex functions of both the manual and oral motor systems, as well as the critical importance of this mechanism for the production of speech and language.

Mouth Asymmetry

Recently, a new methodology for determining the cerebral laterality for speech production has been developed by Graves and colleagues (Graves, 1983; Graves et al., 1982; Graves, Landis & Simpson, 1985; Wyler, Graves & Landis, 1987). The development of a mouth asymmetry methodology allows investigators to determine which side of the mouth is preferentially activated during the production of speech and other oral tasks. During speech production, the right side of the mouth is preferentially activated (Graves et al., 1982). In a series of early studies, Graves et al. (1982) found that 76% of their subjects had a right mouth advantage (RMA) for speech production. A RMA for speech production is consistent with left hemisphere dominance for speech and language. Since the seventh cranial nerve (facial nerve), lies below the level of the pyramidal decussation, the right side of the mouth receives efferent projection from left hemisphere pathways (Van Gelder & Van Gelder, 1990). Thus, left hemisphere dominance for language is expressed via a facilitation of the right side of the mouth for speech tasks due to more direct projections from the dominant left hemisphere. Mouth asymmetry studies have repeatedly shown that during spontaneous speech the extent of right side opening is greater than that of the left (Graves, 1983; Graves et al., 1982)

Although a robust right side bias had been found for speech tasks, many arguments concerning the intuitive validity of the mouth asymmetry methodology and its assessment of cerebral organization have been posed. Specifically, Hager and Ekman (1985a, 1985b) have argued that mouth asymmetry may result from agonist muscle facilitation on the right side of the face during mouth opening. Additional criticisms include a RMA resulting from a preexisting anthropometrical advantage on the right side of the face. Hager and Ekman's (1985a) contention that RMA is the result of agonist muscle facilitation is based on a facial asymmetry study which found that women have a right side bias for facial expressions. The finding is contradictory to numerous studies which have indicated a left side/right hemisphere bias for the expression of emotion (Borod, Caron & Koff, 1980; Campbell, 1978; Moscovitch & Olds, 1982). The results of Hager and Ekman (1985a) may be confounded by their methodology. Subjects were required to make facial expressions based upon a series of submovements, to achieve the target facial expression. Therefore, the expressions were deliberate, as opposed to the spontaneous expressions used in previous research (Chaurasia & Goswami, 1975). As well, the movement complexity and number of overt postural transitions required to complete a deliberate facial expression may have mediated left and right hemispheric involvement during the movement, relying on left hemisphere centers for completing the postural transitions of movements (Kimura, 1977; Wolf & Goodale, 1987).

The second criticism of mouth asymmetry pertains to a belief that a preexisting anthropometrical difference, favouring the right side of the face results in a RMA. Stereophotogrammetric measures of facial asymmetry have not reported a right/left difference in the face at rest (Burke, 1971). As well, Wolf and Goodale (1987) found a RMA in their study which utilized a sensitive digitizing measure that factored out resting facial asymmetry.

Mouth asymmetry for speech and language tasks is present in individuals with severe right side facial paralysis (Graves & Landis, 1985). In a study of 20 right handed subjects with unilateral left hemisphere damage and associated right side facial paralysis, 75% of the subjects displayed a RMA for propositional speech tasks, but not for automated speech or singing. In fact, 11 of the 20 subjects had a resting tendency of the left side of the mouth to be open more due to the facial paralysis, but overcame the resting left side bias to exhibit a RMA during the spontaneous speech task (Graves et al., 1985).

The assertion of Hager and Ekman (1985a, 1985b) that RMA is a right side agonist muscle facilitation has not been supported by mouth asymmetry studies which have determined that the extent of mouth asymmetry is influenced by the nature of the speech task (e.g., Graves & Landis, 1990; Graves et al., 1985, Wyler et al., 1987). For example, on tasks requiring greater spatial, visual or emotional awareness such as describing a picture, a lessening of RMA occurred (Wyler et al., 1987). These results are consistent with the RH specialization for overt emotional expression (Sackeim & Gur, 1978), and its increased spatial processing abilities (Umilta et al., 1985). Graves and colleagues (Graves et al., 1982; Graves et al., 1985; Graves & Potter, 1992; Wyler et al., 1987) have argued that a right mouth bias is facilitated in tasks which require the spontaneous production of the propositional components of speech, while tasks which involve the production of automated speech display a lessening of RMA due to a right hemisphere specialization for the production of automated speech (Graves & Potter, 1992).

The failure of early mouth asymmetry studies was not in identifying a RMA for speech production, but in quantifying the extent of left/right difference. In their initial studies, Graves and colleagues (Graves et al., 1982; Graves et al., 1985; Wyler et al., 1987) employed relatively insensitive measures for quantifying mouth opening by utilizing techniques such as a tangential ruler method and surface electromyography (EMG). The "ruler" method ignored the dynamic actions that occurred during speech production. This method provides only a brief "snapshot" of what occurs during speech production. As well, surface EMG (Graves et al., 1985) which has shown asymmetrical muscle activation favouring the right side of the face is limited by the morphological structure of facial muscles. The thin flat muscles of the mouth overlap one another, making muscle isolation difficult. To account for these methodological difficulties, Wolf and Goodale (1987), utilized a more sensitive methodology for measuring mouth asymmetry, which additionally permitted the quantification of the dynamic movements of the mouth during speech tasks. This study employed frame by frame analysis of the mouth during the production of syllables and non verbal oral movements. Subjects were required to produce oral movements in three conditions: a single movement, a repeated movement and a sequential movement. Frame by frame analysis allowed the experimenters to conclude that RMA is reflected not only at the beginning of lip separation but also at the end of a movement, and that the RMA is present in both the vertical and horizontal mouth separation. Additionally, Wolf and Goodale determined that the extent of the RMA increased in the repeated and sequential movement conditions. The resultant increase in RMA due to movement condition is believed to reflect greater involvement of left hemisphere centers responsible for multiple postural transitions. A strict interpretation of Kimura's hypothesis (1977, 1982) would be that the increased RMA is a result of an increasing involvement of the left hemisphere for correctly sequencing the changes in successive postural positions.

The agonist muscle facilitation theory proposed by Hager and Ekman (1985a) fails to account for the increase in RMA that results from a more complex speech task. Thus, it appears that mouth asymmetry studies are valid in their interpretation of greater RMA due to left hemisphere dominance for speech and language. As well, greater RMA seen in more complex verbal movements may be a reflection of increased left hemisphere involvement in coordinating the spatial-temporal and/or postural transitions required to complete a complex speech action (e.g., Kimura, 1977; Roy & Storer, 1985; Wolf & Goodale, 1987).

Another methodology used to assess the organizational control for speech on the right side of the mouth is to perturb either the left or right side of the mouth during a speech task (Cadalbert et al., 1994; Graves & Potter, 1990). The quality of speech articulation has been found to be diminished when the right side of the mouth is "pinched", while left side "pinching" does not result in a disruption in the quality of speech articulation.

Down Syndrome

A general understanding of cerebral organization in special populations provides an opportunity to gain insight into the mechanisms which limit the cognitive and physical functioning of a given subset of individuals. Individuals with Down syndrome (DS) are impaired in their cognitive and physical functioning as a result of a triplication of the 21st chromosomes (Kandell, Schwartz & Jessell, 1991). The resultant deficits seen within a DS population always include moderate to severe mental retardation and diffuse language deficits (Bullock & Rosendahl, 1992).

Language impairments in DS may result from a wide number of neurological and chemical impairments within the DS brain (Tanzi, 1996). Postmortem analyses and invivo imaging techniques have shown that the DS brain is significantly atrophied, with marked decreased volume in the dorsolateral prefrontal, or speech region (Raz, Torres, Briggs, Spencer, Thornton, Loken, Gunning, McQuain, Driesen & Acker, 1995; Ross, Galaburda & Kemper, 1984; Wisniewski, Laure-Kamionowska, Connell & Wenn, 1986). The reduced volume of the DS brain may account for some of the cognitive and language impairments seen in DS. However, it is unlikely that the wide spectrum of impairments in DS is specifically related to decreased functional area within the cerebrum. Persons with DS have a discriminant metabolic function within the cerebrum reflecting an abnormal interaction between the primary language areas (Azari, Horwitz, Pettigrew, Grady, Hacby, Giacometti, & Schapiro, 1994). These results suggest that the language impairments in DS are not related to one specific factor, but are the result of a more global cerebral impairment.

The cerebral specialization for speech and language in persons with DS has been studied to determine if there is a relationship between cerebral organization and developmental deficits. Specifically, cognitive deficits may result due to several incomplete stages of development where the proliferation of neurons, cell differentiation and organization are altered or impaired (Guberman, 1993). A lack of cell specialization, may prevent language from lateralizing to a dominant hemisphere, thereby resulting in language impairments. Lennenberg (1967) has proposed that language lateralizes with development. Therefore, the lack of cellular cytoarchitectonics in the cerebral cortex in persons with DS may inhibit the lateralization and development of cognitive functions within the cerebrum.

Based on Lennenberg's (1967) theory of developmental lateralization, Sommers and Starkey (1977) hypothesized that individuals with DS would not be lateralized for speech and language in the same way as individuals without DS. To test this hypothesis, a dichotic listening procedure was used to determine the cerebral dominance for speech perception. Consistent with Lennenberg's theory of development, Sommers and Starkey found that children and adolescents with DS did not display an ear advantage for meaningful words, suggesting a lack of cerebral specialization for the perception of speech. Sommers and Starkey's findings have been challenged by several researchers who have found an ear advantage (Elliott & Weeks, 1993; Giencke & Lewandowski, 1989; Hartley, 1981; Hartley, 1982a; Hartley, 1982b; Pipe, 1983; Zekulin-Hartley, 1982). These researchers report a left ear advantage for the perception of verbal material in young children and adolescents with DS. Indeed, Elliott, Weeks and Chua (1994) analyzed the nine published reports on this topic. The meta analysis revealed that persons with Down syndrome have a left ear dichotic advantage. Thus, unlike the normal population, who have a right ear/left hemisphere advantage for speech perception, individuals with DS have an atypical left ear/ right hemisphere advantage for this task. The finding was not replicated by Tannock, Kershner and Oliver (1984) who employed a selective attention methodology in their dichotic listening study. Tannock et al. have suggested that a reversal in ear advantage found in previous studies is the result of "situational specific factors" which preferentially activated the right hemisphere. Thus, Tannock et al. concluded that an atypical ear advantage is not a syndrome specific pattern of behaviour in DS. As well, Parlow, Kinsbourne and Spencer (1996) have similarly reported that an atypical ear advantage is not present in middle aged individuals with DS. However, support for the findings of both Tannock et al. and Parlow et al. (1996) is cautioned due to potential methodological flaws, limiting the application of their results to the DS community. Specifically, Tannock et al. did not use a control group to determine whether their results were similar to non DS subjects. In contrast Bowler, Cuffin and Kiernan (1985) who used the same "selective attention" method as Tannock et al. found a small left ear advantage for the DS group, compared to a strong right ear advantage for a non-DS group. Parlow et al. utilized a low functioning group of middle aged DS subjects in their study. Since neuropathological changes are severe in individuals with DS over the age of 30 years (Tanzi, 1996) the tasks demands and ear advantage may be a reflection of pathological age changes and a poor verbal comprehension of task demands. Parlow et al. reported a chance level of 33% (for 1 stimulus), thus the probability of guessing one of the stimuli correctly on a given trial was relatively high.

The atypical left ear advantage for speech perception has led Hartley (1981) to propose a model of reversed cerebral organization in Down syndrome. The model proposes that individuals with DS have a right hemisphere dominance for language functions, which can account for some of their verbal deficits.

This basic model of reversed cerebral specialization (Hartley, 1981) has proven too simplistic in describing the neurobehavioural characteristics of persons with DS. Elliott and colleagues (Elliott, 1985; Elliott, Weeks & Jones, 1986; Elliott, Weeks & Elliott, 1987; Elliott, Weeks & Gray, 1990) have attempted to reconcile the issue of cerebral organization in DS through a series of studies examining manual asymmetries. Elliott (1985) examined the rapid finger tapping performance of non-retarded subjects, undifferentiated mentally retarded subjects and individuals with DS. As expected, the non-retarded group displayed a right hand superiority for this task (Todor & Kyprie, 1980, 1982). The DS and retarded groups failed to show a manual asymmetry favouring the right hand. However, in a follow-up study which included a measure of finger-tapping variability, which has been shown to be a more sensitive measure for determining manual asymmetries (Todor & Kyprie, 1980), participants in the DS group did exhibit a right hand superiority (Elliott et al., 1986). On the basis of these preliminary results the simple model of reversed cerebral specialization proposed by Hartley (1981) appears too simplistic in its attempt to describe the cerebral organization of persons with DS.

Transfer of training studies typically find greater transfer from the left hand to the right hand for sequential movements (Taylor & Heilman, 1980). The asymmetrical transfer is assumed to reflect a left hemisphere dominance for the organization and control of sequential movement. Thus, when practicing with the left hand, the right cerebral hemisphere is actively controlling the contralateral musculature in the left hand, while at the same time the centers in the left hemisphere responsible for sequential movements are also participating in the control of the movement (Todor & Kyprie, 1982). Thus, when transferring to the right hand, whose musculature is controlled by the left hemisphere, the prior exposure of the left hemisphere to this task facilitates its ability to perform the task. When the transfer of training paradigm was applied to individuals with DS, the same pattern of asymmetrical transfer in learning occurred (Edwards & Elliott, 1989).

Another method to determine cerebral specialization for movement organization is the dual task paradigm (Kinsbourne & Cook, 1971). The dual task paradigm involves the concurrent production of an oral and manual task. Manual performance such as dowel balancing or sequential typing combined with concurrent verbal production depresses right hand manual performance more than left (Kinsbourne & Cook, 1971; Lomas & Kimura, 1976). The interaction between speaking and manual activity is believed to result from a shared left hemisphere system, responsible for both skilled manual and oral movements (DeRenzi et al, 1966; Kimura, 1982, Square-Storer, Qualizza, & Roy, 1989). Elliott et al. (1987) employed an interference paradigm to assess the performance of persons with DS. As expected, right hand performance was significantly depressed compared to left hand performance in the concurrent activity, which was similar to a group of control subjects of similar chronological age (see also Piccirilli, D'Alessandro, Mazi, Sciarma & Testa, 1991).

The research so far has indicated that persons with DS demonstrate an anomalous right hemisphere specialization for speech perception (e.g., Hartley, 1981) coupled with a typical left hemisphere specialization for the control of sequential movement (e.g., Elliott et al., 1986). The apparent dissociation between the centers responsible for speech perception and movement execution result in a disconnection between the functional cerebral space subserving the two functions (Kinsbourne & Hicks, 1978). The dissociation (Geschwind, 1965) can account for the cognitive problems associated with the perception of speech coupled with the control of complex movements including speech production. Based on the findings from manual asymmetry studies, Elliott et al. (1987) have proposed a model of biological dissociation. The model postulates that a disconnection exists between the right hemisphere systems responsible for speech perception and the left hemisphere centers responsible for movement execution. The disconnection results in a diminished quality of information reaching the effector centers in the left hemisphere due to interhemispheric transmission.

To test the model, a variety of methodologies have been employed. Elliott et al. (1990) administered an apraxia battery to groups of control, undifferentiated mentally retarded, and DS subjects. Subjects were required to complete an apraxia battery developed by DeRenzi et al. (1966). The apraxia battery consisted of manual and oral movements performed in isolation (e.g., "tap a finger" or "stick out your tongue") and in sequences of two or three movements (e.g., "drink water, snap fingers and clap hands"). When the modality of input was given via a visual command, the DS and mentally retarded group did not differ with respect to the number of errors made. However, when the modality of input was verbal, the DS group demonstated a significantly greater number of order and substitution errors when compared to the undifferentiated mentally retarded group. These data indicated that movement impairments are related to the number of sequences, but more specifically the modality of input.

In an analysis of the effects of advanced information on the programming of a simple movement, it was demonstrated that the reaction time for indivduals with DS were no longer than controls when producing a movement based on information from a valid visual precue. However, during a verbal precue the DS group was significantly impaired relative to an undifferentiated mentally handicapped and control group (LeClair & Elliott, 1995). The results of the apraxia battery and advanced information studies provide additional support for the model of biological dissociation. In keeping with the predictions of the model, individuals with DS are more impaired when a movement must be executed on the basis of verbal information perceived by the right hemisphere.

The purpose of the present study was threefold. The first purpose was to determine the cerebral lateralization for speech production in adolescents and young adults with DS. This study was the first to investigate lateralization for the production of speech in persons with DS using the mouth asymmetry methodology. As mentioned previously, speech perception is thought to be lateralized within the right hemisphere of individuals with DS (Hartley, 1981; Elliott & Weeks, 1993), the attempt in this study was to determine if the speech production is lateralized to the left hemisphere. Based on the model of biological dissociation (Elliott et al., 1987), persons with DS were expected to display a right mouth bias for speech tasks, due to a left hemisphere dominance for speech production.

The second purpose was to determine how complex movements, and movement transitions affect the degree of mouth asymmetry in DS. Since the neural mechanisms which underlie oral and manual movements are believed to be similar (DeRenzi et al., 1966; Kimura, 1982; Square-Storer et al., 1989) movements which require greater spatial-temporal coordination of the articulators were anticipated to result in a greater right side bias for the speech task. An increased RMA in more complex oral movements is believed to be a result of greater left hemisphere activation (Wolf & Goodale, 1987). In more complex verbal tasks, the interaction of left hemisphere centers for speech production and complex movements/postural transitions are believed to result in an increased right mouth bias. An increased RMA for both movement repetition and movement transitions would support the theory of a left hemisphere mechanism dominant for the spatial-temporal coordination of higher order movement complexity (Kent & Rosenbek, 1983; Roy et al., 1989; Roy, 1985). In contrast, if the extent of the RMA was greater for movements requiring more postural transitions, as opposed to movement repetitions, then the theory of a left hemisphere system responsible for movement transitions would be supported (Kimura, 1977; Kimura, 1982; Ojemann & Mateer, 1979). Thus, two final motor pathways, one for repeated movements and the other for sequential movements should be identifiable based on the extent of a RMA (Ojemann & Mateer, 1979). A RMA in the DS group would also demonstrate that the movement executive system for verbal movements are localized to the left hemisphere, consistent with the model of biological dissociation (Elliott et al., 1987).

Lastly, the type of errors made by persons with DS during the production of a speech task were quantified by an error notation system. Based on the model of biological dissociation (Elliott et al., 1987), persons with DS were expected to be impaired on more complex oral movements due to the functional separation of the centers responsible for speech perception and motor execution. As well, movements requiring the serial ordering of multiple submovements should produce more errors than the repetition of the same movement. On the basis of these results one can speculate that speech in persons with DS is disrupted in part due to a faulty left hemisphere mechanism responsible for the sequential ordering of the oral articulators (Kimura, 1982; Wolf & Goodale, 1987). As well, persons with DS may have an impaired ability to: "phase" the spatial-temporal components of a neuromuscular event such as speaking, where the discrete elements involved in several submovements are distorted as the length and complexity of a movement increases (Kent & Rosenbek, 1983; Mateer & Kimura, 1977; Square-Storer et al., 1989).

Method

Participants

Ten individuals with Down syndrome and ten non-handicapped subjects matched for chronological age and gender participated in this research (Table 1). It was essential that all subjects were right hand dominant. Hand preference for subjects with DS was determined by placing a pen and paper, a spoon, a ball, and a hammer directly in front of seated subjects. Subjects were then asked to print their name, eat soup, throw a ball, and hammer a nail. Non-handicapped subjects were asked only to indicate their hand preference for the above tasks.[1] A right hand preference for each task was mandatory for participation.

Insert Table 1 about here

Subjects were informed that the purpose of the study was to measure how the muscles of the face moved during speech, and thus, were not aware that left/right differences were being compared. Any subject reporting a history of facial injury or paralysis was excluded from the study.

DS subjects were recruited from a Learning Centre and Special Olympics swim team in the Hamilton-Wentworth area. Subjects were not karyotyped, thus the sample consisted of people with the DS phenotype. Given that 95% of DS cases are the phenotype of trisomy 21, the likelihood of including a subject with mosaicism was low (Guba, 1983). Prior to data acquisition an audiometry test and the Peabody Picture Vocabulary Test (PPVT) were administered. Only those subjects with a pure tone audiometry score within the range of normal for the speech frequencies were included in the study. The PPVT was used to assess the mental age of individuals with DS (Table 1).

Procedure

During the experimental session, subjects were seated in a customized chair facing a camera. The chair was equipped with a contoured foam head rest and a head restraining device, which restricted anterior-posterior and lateral displacement of the head. A Sony TR42 8 mm camcorder filming at high speed mode (60 Hz) provided up close images of the mouth and nose of subjects. The auditory performance was recorded by a microphone built into the camcorder. Two 110 Watt floodlights placed 2 m away from subjects at an angle of 45 degrees were used to increase the contrast around the mouth area. Subjects were protected from the resultant brightness by a pair of dark sunglasses.

Washable black eyeliner pencil was used to outline subject's lips and to draw ten markers about the lips, and two reference points on the nose (Figure 1). For the DS subjects, a second experimenter was present to model the make-up procedure, and to ensure that the subjects were at ease with the make-up application. The markers and reference points were used as digitizing points in later analysis.

Insert Figure 1 about here

The experimental task consisted of combining the bilabial phonemes ("M", "B", and "P") with one of two vowels ("a", "i"), producing the syllables "Ma", "Ba", and "Pi". Bilabial phonemes are the best sounds for a verbal task of this nature because the lips were closed prior to phoneme production. The syllables were produced in three different experimental conditions: single, repeated, and sequential. In the single conditions, subjects were required to produce the target syllable once (e.g., "Ma"), in the repeated condition subjects were required to repeat the target syllable approximately ten times at a rate of 1 syllable per second until they were given a stop command by the experimenter (e.g., "Ma, Ma, Ma, Ma, Ma.....). In the sequential condition, phonemes were combined to produce a string of target syllables requiring a series of postural readjustments (e.g., "Ma Ba Pi, Ma Ba Pi, Ma Ba Pi...."). The phoneme string was repeated approximately 7 times per trial at a rate of 1 string per 2.5 seconds. For each condition 10 trials were performed, producing a total of 90 trials.[2] At the beginning of each trial, subjects were given a verbal instruction about the syllable and condition to be performed. For instance, in the sequential condition subjects were instructed by the experimenter to "Repeat 'Ma Ba Pi' until I tell you to stop", for the repeated condition subjects were instructed to "Repeat 'Ma' until I tell you to stop", while in the single condition subjects were instructed to "Repeat 'Ma' once".

Video Tape Analysis

The videotaped trials were analyzed using a Peak Performance movement analysis system. Peak provided stable frame by frame advancement of images. The Peak Performance system was linked to a microcomputer which stored the raw pixel values as x, y, and z co-ordinates. The video image was converted to a black and white text data image on a Panasonic CT 1400 MG data monitor which provided an image of the mouth and nose enlarged two times that of real life. Two reference markers were placed on the nose (due to the minimal displacement of the nose during a speech task) to ensure that extraneous head movements during data acquisition did not confound the results. In the case of an extraneous head movement, the lip markers would be rotated and translated to an extrapolated position, based on the initial position of the two reference markers. Pilot work in this area showed that the head restraining device inhibited almost all head movement for the control group. However, reference points were maintained throughout the study because maintaining a stable head position proved difficult for some participants with DS.

Prior to experimental data analysis, resting measures of the mouth were calculated for each subject, to ensure that subjects did not have a preexisting anthropometrical difference favouring the left or right side of the mouth. Ten frames in which the lips were together and not in preparation for a movement were digitized. These resting mouth values were later subtracted from initial and maximum aperture scroes to factor out any resing facial asymmetries. Comparisons were made between left/right vertical and left/right horizontal resting measures of the mouth. Measures of left/right vertical values were calculated by determining the distance between points 2 & 3 on the right, and comparing it with points 6 & 7 on the left side of the mouth (Figure 1). Horizontal measures for the right side of the mouth were determined by calculating the average of the distance between bottom midline positions 4 & 1, with top midline position 5 & 1. This value was then compared to the corresponding values on the left side of the mouth (e.g., 4 & 8 / 5 & 8).

A comparison between the amplitude and velocity of movements on the left and right sides of the mouth were calculated with respect to both the vertical and horizontal dimension. The dependent variables analyzed were: initial lip aperture, maximum lip aperture, maximum velocity and total marker movement. Initial aperture was defined as the change in mouth displacement from Frame No. 1 to Frame No. 2 (frame of lip separation). Maximum aperture was the change in displacement from Frame No. 1 to the frame of maximum mouth opening, typically about Frame No. 8. The maximum change between two consecutive frames was defined as maximum velocity, while total marker movement was a comparison of the maximum displacement of individual vertical markers 3 and 7, and horizontal markers 9 and 10. An analysis of the movement of upper lip markers 2 and 6 was not included because the degree of movement was not large enough to provide a clear trend. As well, an analysis of initial aperture with this measure would have been redundant.

Vertical Displacement

The displacement of points 6 & 7 (left) and 2 & 3 (right) were calculated individually and as part of linked segments to determine the extent of left/right differences in the vertical direction. Initial and maximum aperture were calculated by determining the distance between points 6 & 7 (left) and comparing it with 2 & 3 (right). Right (R) and Left (L) displacements were used to calculate an asymmetry ratio (R-L/R+L). A positive value reflects greater right side opening, while a negative value indicates a greater left side opening.

Horizontal Displacement

As previously mentioned horizontal values for the left side of the mouth were calculated by determining the distance between points 4 & 10 and 5 & 10. Similarly for the right, the distance between points 4 & 9 and 5 & 9 were used to calculate the extent of mouth opening in the horizontal direction. An asymmetry ratio (R-L/R+L) was independently calculated for the bottom of the mouth (for both the right and left side) and then averaged with the corresponding side value for the top of the mouth, before a comparison of right/left horizontal differences were made.

Reliability Measures

The reliability of digitizing was assessed by comparing the values attained on two successive measures of the same trial. Ten randomly selected trials were used for this analysis. Later, two of the trials were used to calculate the intraclass correlation coefficient for test-retest reliability. Corresponding axial co-ordinates were compared with one another. For example, the y co-ordinates for point 3 on the two trials were compared with one another. This is because point 3 moves significantly only in the vertical dimension, making a comparison of the x co-ordinate unnecessary. The intraclass correlation coefficient for point 3y yielded a value of (r_{intra} = 0.91). The intraclass correlation coefficients for all relevant points are reported in Table 2.

Insert Table 2 about here

Verbal Errors

Speech fluency errors in the DS group were evaluated from the audio portion of the videotaped analysis. Phonemes were not digitized if the production consonant differed from the goal consonant. Speech fluency was evaluated by determining the types of errors committed in the sequential verbal condition. In the sequential condition the first, second and third phoneme strings were assessed for fluency errors (whereas, only phoneme 1 and 7 were digitized). The first error to occur in a syllable string was recorded, subsequent errors within the string were not included in the analysis. The error notation system [3] (Square et al., 1989) incorporated 8 different behaviours subdivided into six categories (see Appendix 1). All fluency measures were evaluated by one experimenter (M.H.). The reliability of error classification was assessed by analyzing the results of one subject on two separate occasions. The resultant phi coefficient (Ø = 0.64) demonstrated that there was a moderate to high consistency in properly coding errors. As well, the proportion of agreement for categorization of errors was 82%, with a corresponding coefficient of agreement (k=0.65).

Data Analysis

In the single, repeated and sequential movement conditions the first phoneme produced was always digitized (Single 1, Sequential 1, Repeated 1). As well, the seventh phoneme in the Sequential and Repeated conditions was also analyzed (Sequential 3, Repeated 7). These embedded movements were used to assess the change in RMA due to movement complexity (see Table 3)

Insert Table 3 about here

All dependent variables were independently analyzed using a 4 way mixed design ANOVA: Group (Non-handicapped, Down syndrome) X Side

(Left, Right) X Context (Sequential 1, Repeated 1, Single, Sequential 3, Repeated 7) X Phoneme (Ma, Ba, Pi). Post-hoc analyses (Tukey HSD, $p < .05$) were used to examine any significant differences between levels of any main effects and interactions involving more than two means. Each dependent variable (initial aperture, maximum aperture, maximum velocity, total marker movement) was independently assessed for displacement in the vertical and horizontal dimension.

Results

Resting Mouth Values

Resting mouth values were analyzed using an independent samples t-test. The resting mouth values for both the vertical ($t(18) =.89$, $p=.12$) and horizontal ($t(18) =.18$, $p=.38$) dimensions did not show any significant difference between the resting mouth values of the non-handicapped and DS group.

Measures of initial vertical values

The increase in displacement in the vertical dimension of the mouth from Frame No. 1 to Frame No. 2 did not result in significant findings for group, $F < 1.0$, or side, $F < 1.0$, which indicated that during the first 16.7 msec of movement, groups were indistinguishable (non-handicapped = 0.80 cm, DS = 0.52 cm). The findings for side, although nonsignificant ($p = 0.21$), revealed a trend that was consistent throughout the analysis of all variables in the vertical and horizontal dimension. Specifically, the displacement of the right side of the mouth (right = 0.69 cm), was larger than that of the left (left = 0.64 cm). The analysis of vertical initial aperture did not produce significant effects for context or phoneme.

Measures of maximum vertical values

The analysis of maximum aperture demonstrated a main effect for group, F(1,18) = 5.86, p = .02, and context, F(4,72)= 8.10, p < 01. Additionally, an interaction for group x context x phoneme, F(8,144) = 2.27, p = .02, was found. The main effect for group (Figure 2) illustrated that non-handicapped subjects (2.23 cm) had a larger final mouth position than participants with DS (1.44 cm).

Insert Figure 2 about here

Moreover, the type of movement influenced the degree of mouth opening (Figure 3). The amplitude of movements in the Repeated 7 condition were significantly less than Sequential 1, Repeated 1 and Single conditions, but did not differ from the other embedded movement condition, Sequential 3. As well, Single movements were greater in overall amplitude than all movements embedded within a series (e.g., sequential 3 and repeated 7).

Insert Figure 3 about here

Although the average value for the right (2.23 cm) tended to be larger than the left (1.44 cm), no overall effect for side was evident, $\underline{F} < 1.0$ The group x context x phoneme interaction indicated that the final size of mouth opening in the non-handicapped group was larger than the DS group, except when the DS produced the phoneme "Ma" in the Single condition. For this movement the mouth size for individuals with DS was similar to subjects in the non-handicapped group for the production of "Ba" in the Sequential 3 and Repeated 7 conditions and "Pi" in the Sequential 3 condition. Additionally, the amplitude of movements within the DS group varied depending on the movement condition and phoneme production. The final mouth size for the phoneme "Ma" in the Repeated 1 and Single conditions was larger than that produced during the production of "Ba" during a Repeated 7 task. As well, the production of Single "Ma" by the DS group resulted in significantly larger mouth opening than for "Ba" during a Repeated 1 condition.

Analysis of vertical total marker movement revealed a main effect for context, $\underline{F}(4,72) = 10.39$, $\underline{p} < .01$, a side x phoneme interaction, $\underline{F}(2,36) = 9.29$, $\underline{p} < .01$, and a four way interaction between group x side x context x phoneme, $\underline{F}(8,144) = 3.19$, $\underline{p} < .01$. The main effect for context illustrated that the final position of the lower lip was greater for Single movements than any of the other movement conditions. Repeated 7 movements tended to have the least displacement, which did not differ significantly from the embedded movements in the Sequential 3 condition.

The side x phoneme interaction showed that production of the phoneme "Pi" resulted in an RMA , that was significantly larger than the RMA occurring for the production of the phoneme "Ma". A RMA was not present during the production of the phoneme "Ba". Overall, the phoneme "Pi" resulted in the largest left-right difference (Figure 4).

Insert Figure 4 about here

The group x side x context x phoneme interaction indicated that the amplitude and asymmetry in the non-handicapped group during the production of the phoneme "Ba" during the Repeated 7 condition was similar to the overall amplitude of the DS group. However, the degree of RMA was greater for individuals with DS in this condition than for non-handicapped subjects (see Table 12 in Appendix B).

Measures of maximum vertical velocity

Analysis of maximum velocity revealed significant main effects for context, $F(4,72) = 11.64$, $p < .01$, phoneme, $F(2,36) = 4.39$, $p = .01$, and a side x phoneme interaction, $F(2,36) = 4.26$, $p = .02$. The velocity for Single movements resulted in significantly greater values when compared to the other movement conditions. Maximum velocity for Repeated movements (Repeated 1 and Repeated 7) differed significantly, with Repeated 1 (.45 cm/frame) movements achieving greater overall velocity compared to the Repeated 7 (.41 cm/frame) condition. Mouth velocity was affected by phoneme production, the phoneme "Ma" was significantly faster than "Ba", but did not differ from "Pi". This result is consistent with the phoneme "Pi" having the largest displacement (Figure 5).

Insert Figure 5 about here

The side x phoneme interaction demonstrated that the phoneme "Pi" had the largest left/right difference favoring the right side of the mouth, followed by the phoneme "Ma". The production of "Ba" resulted in the smallest left-right difference (Figure 6).

Insert Figure 6 about here

Measure of initial horizontal values

The initial horizontal lip displacement revealed a significant main effect for side, $\underline{F}(1,18) = 5.16$, $\underline{p} = .03$ which illustrated that in the first 16.7 msec of movement the right side (1.16 cm) of the mouth opened wider than the left (0.99 cm). This result provides firm evidence that at the beginning of a speech task both the control and DS group have a RMA (Figure 7). No further main effects or interactions occurred for initial horizontal displacement.

Insert Figure 7 about here

Measures of maximum horizontal values

At the end of a movement the values for maximum aperture revealed main effects for group, $F(1,18) = 7.30$, $p = .01$, side, $F(1,18) = 7.71$, $p = .01$, and phoneme, $F(2,36) = 6.17$, $p < .01$. As well, there was a group x context x phoneme interaction, $F(8,144) = 3.24$, $p < .01$. Similar to the vertical maximum aperture results, the control group (2.74 cm) opened their mouths wider than the DS group (2.17 cm). As hypothesized, at the end of a movement there was a significantly larger right side opening (2.56 cm) compared to the left (2.36 cm) for both groups (Figure 8).

Insert Figure 8 about here

The main effect for phoneme indicated that the type of phoneme influenced the size of the mouth opening. The phoneme "Pi" resulted in the largest mouth opening (2.53 cm) which was significantly larger than the phoneme "Ba" (2.36 cm), but did not differ significantly from "Ma" (2.46 cm). The group x context x phoneme interaction suggested that for most phonemes and movement conditions the overall amplitude of movements for the non-handicapped group was significantly larger than the DS group, except for the production of "Ma" in the Single movement condition. For this phoneme the size of the mouth opening was not statistically different from the non-handicapped groups production of "Ba" at the Repeated 1 or Sequential 3 condition, or the production of "Ma" at the Sequential 1 condition.

Analysis of total marker movement produced an effect for side that approached the conventional levels of significance, $\underline{F}(1,18) = 4.27$, $\underline{p} = .053$, as well as a main effect for phoneme, $\underline{F}(2,36) = 4.08$, $\underline{p} = .02$. Although the difference was not statistically significant, the right side (3.59 cm) opened more than the left side of the mouth (3.39 cm). Production of the phoneme "Pi" resulted in the greatest mouth opening (3.57 cm) followed by "Ma" (3.47 cm) and "Ba" (3.42 cm). The latter two phonemes did not differ significantly from one another.

Measures of maximum horizontal velocity

Significant main effects or interactions did not occur in the analysis of maximum velocity in the horizontal dimension. However, as consistently demonstrated in all variables, there was a trend toward the right side (1.86

cm/frame) having a greater rate of change than the left side (1.76 cm/frame) of the mouth occurred ($p = 0.12$).

Left-Right vertical and horizontal ratios

Although an analysis of variables in the vertical dimension did not result in a statistically significant RMA, a definite trend for greater opening on the right side was present at the beginning and end of movement. The results for the horizontal dimension portrayed a clear RMA for both the beginning and end of a movement. Thus, the dependent variables initial aperture and maximum aperture were used to calculate an asymmetry ratio (R-L)/(R+L) for both the vertical and horizontal dimensions. Most ratio scores were positive, indicating greater right side opening. However, the absolute values for all conditions were used in the analysis to determine whether the degree of asymmetry between the non-handicapped and DS group differed. The absolute values were used because the direction of asymmetry between the two groups had previously been assessed using displacement measures.[4] A Group (Non-handicapped, DS) X Context (Sequential 1, Repeated 1, Single) X Phoneme (Ma, Ba, Pi) mixed ANOVA was calculated. The initial vertical and horizontal ratios did not reflect a magnitude difference in asymmetry between groups, $\underline{F} < 1.0$. As well, the maximum vertical and horizontal ratio values did not differ with respect to group, $\underline{F} < 1.0$. Therefore, even in cases where a RMA was present (i.e., horizontal maximum aperture) the asymmetry ratio was unable to detect a difference in the degree of lateralization between the non-handicapped and DS group. The trend for ratio values ($p = 0.37$) was that (non-handicapped = 0.05) had a smaller direction of asymmetry than the DS group (0.06). This result provided strong evidence that the sample size used in the current investigation was large enough to detect group differences, since the ratio values were actually larger for persons with DS.

Measures of initial vertical and horizontal variability

Initial vertical variability was examined by analyzing within-subject standard deviations in initial aperture. A Group (control, DS) X Side (Left, Right) X Context (Sequential 1, Repeated 1, Single, Sequential 3, Repeated 7) X Phoneme (Ma, Ba, Pi) mixed ANOVA was used to analyze potential main effects or interactions of this variable. Analysis of vertical variability for initial aperture yielded a significant group x context $F\ (4, 72) = 4.39$, $p < .01$ interaction. Sequential 3 movements made by non-handicapped subjects were significantly less variable than Repeated 7 movements made by subjects in the DS group. The variability differences between groups at all other levels of movement context were not reliable in either the vertical or horizontal dimensions. The absence of a significant group effect for vertical, $F < 1.0$ and horizontal, $F < 1.0$, dimensions indicated that variability between the non-handicapped and DS group did not differ significantly during the first 16.7 of lip separation.

Measures of maximum vertical and horizontal variability

The within-subject standard deviation of maximum aperture as well as total marker movement were used to examine the variability associated with the end of a movement. Analysis of vertical variability for maximum aperture and total marker movement did not yield any significant main effects or interactions. However, the analysis of horizontal variability in maximum aperture resulted in a main effect for group, $F(1,18) = 7.23$, $p = .01$, as well as a group x side interaction, $F(1,18) = 6.43$, $p < .02$. The group effect suggested that displacement associated with reaching the end of a speech movement was more variable within the DS group. Thus, non-handicapped subjects were more consistent reaching or terminating the end of a movement (Figure 9).

Insert Figure 9 about here

The group x side interaction indicated that the end variability associated with the right side of the mouth in the DS group, was significantly greater than the variability for either the left or right side in the non-handicapped subjects (Figure 10).

Insert Figure 10 about here

Analysis of total marker movement revealed a similar group pattern for variability, $F(1,18) = 9.16$, $p < .01$, indicating that the DS group is more variable reaching the end of a movement (Non-handicapped = 0.28, Down syndrome = 0.40)

Measure of vertical and horizontal variability in maximum velocity

Analysis of vertical maximum velocity within-subject standard deviation did not yield any significant main effects or interactions. However, a main effect for group in the horizontal maximum velocity occurred, $F(1,18) = 9.16$, $p < .01$, demonstrating that subjects with DS were more variable than non-handicapped participants.

Analysis of Verbal Errors

The verbal performance of 8 individuals with Down syndrome were assessed for fluency errors [5] (see Appendix A). Fifty percent of the phoneme strings were produced incorrectly by individuals with DS. Analysis of responses for the sequential speech task revealed three major types of errors: (a) Substitution errors (46%)-intrusion of a consonant or vowel that preceded or followed the target syllable, (b) Mispronunciation errors (29%)-inappropriate production of the target syllable (e.g., “Mom” instead of “Ma) and (c) Pausing errors (19%)-situations in which the experimenter had to initiate a second prompt if the subject had not begun the speech task within 3 seconds of the initial prompt. Repetition (5%) and Timing (1%) errors accounted for a small percentage of the errors (Table 4).

Insert Table 4 about here

Discussion

The purpose of the present study was to develop and utilize a sensitive technique to quantitatively describe mouth asymmetry during a speech production task. Based on previous mouth asymmetry studies, a RMA for non-handicapped individuals was anticipated. As well, individuals with DS were expected to display a pattern of mouth asymmetry similar to the control group. This hypothesis was based on the model of biological dissociation's prediction that speech production is lateralized to the left hemisphere in persons with DS (Elliott et al., 1987).

The results of the present investigation support those of previous mouth asymmetry studies. Specifically, a right mouth advantage (RMA) occurred during a speech production task. In their initial work, Graves and colleagues (Graves et al., 1982; Graves, 1983; Graves & Landis, 1985) focused their research on manipulating the task demands of different speech and language acts. Propositional speech and the phonological constructs required for its production are lateralized to the left hemisphere, and resulted in the largest left-right difference, or RMA. Tasks such as automated speech (i.e., counting), visual description and singing, which involve different and more diffuse areas of cerebral representation, resulted in a lessening of the RMA. This phenomenon was attributed to greater right hemisphere activation for the latter tasks. Indeed, the results of the present study correspond to the assertion that a RMA results from the left hemisphere's direct access to the right side of the face via contralateral cerebral pathways. Since the right side of the face is controlled by the left hemisphere, information and innervatory patterns for the lips and mouth facilitate a right side opening. A left side facilitation does not result because of indirect access by the left side of the face to information in the left hemisphere (Van Gelder & Van Gelder, 1990). A recent study (Cadalbert et al., 1994) has been able to replicate Graves et al. (1982) and Graves et al. (1985) earlier findings, which has extended the validity of the mouth asymmetry methodology for language tasks.

The vast majority of research employing the mouth asymmetry paradigm has focused primarily on spontaneous or free speech in order to gauge the neurobehavioural systems dominant for language. This study and work by Wolf and Goodale (1987) deviated from previous mouth asymmetry studies in that participants were required to produce specific syllables (e.g., scripted speech). Wolf and Goodale also had their subjects produce a series of non-verbal oral movements. The current results and those of Wolf and Goodale coincide with earlier findings involving spontaneous language production; that is, subjects displayed a RMA.

Understanding why similar findings occurred for speech and language production tasks can be accomplished through a systematic understanding of the differences between language generation and simple speech production. In Graves et al. (1982), subjects were required to produce spontaneous language, defined as the "internal selection and manipulation of representational symbols (e.g., words, phonemes), and to apply this internal selection to the rule based system which governs the arrangement of the representational symbols" (Square, Roy, & Martin, 1997, p. 2). The output in the current study and that used by Wolf and Goodale (1987) was a scripted speech production task in which subjects were required to reproduce phonemes. The task did not involve the utilization or selection of the representational units of language. Speech is defined as, "a sensorimotor behaviour involving a movement pattern developed through an innervatory process" (Square et al., 1997, p. 2). Thus, language and speech production are separable by their task components. What is similar to both functions is that their cerebral control is lateralized to the left hemisphere (Roy & Square, 1985). In the case of Wolf and Goodale and the work reported here, the RMA cannot be attributed to the left hemisphere dominance for language. Instead the RMA probably resulted from left hemisphere superiority for programming and controlling speech production (Kimura, 1982; Roy & Square-Storer, 1990).

This is not to say that the speech production task did not involve some fundamental input from language centers, but, it is more probable that the phoneme production task relied upon the movement production and execution centers in the left hemisphere dominant for speech production.

As mentioned previously, the present study found a definite RMA for the speech production task in the horizontal dimension (e.g., Graves et al., 1982; Graves et al., 1985). A significant RMA for vertical measures was not elucidated (cf. Wolf & Goodale, 1987), however a strong trend favoring greater right than left mouth opening was present in the analysis. Interpretation of the combined horizontal and vertical values indicated that a RMA for speech production was tenable using the current methodology.

Mouth Asymmetry and Down Syndrome

Although a large body of research has been devoted to understanding the cerebral laterality for speech perception in persons with DS, very little attention has been paid to speech production. Hartley (1981, 1982) and Pipe (1983) found a reversed pattern of speech perception in children and adolescents with DS. To account for this atypical finding Hartley (1981) proposed a model of reversed cerebral specialization in DS, based on the results of dichotic listening studies. This model was ineffective in describing the cerebral specialization in persons with DS, as more recent research has suggested that many functions such as manual asymmetries are lateralized similar to non-handicapped persons (see Elliott & Weeks, 1993, for review).

Elliott and colleagues, who dealt primarily with manual asymmetries in DS, found that like non-handicapped right handed subjects, right handed individuals with DS display a right hand advantage for manual tasks (Elliott et al., 1986). Therefore, the cerebral representation for manual asymmetries in persons with DS reflects a similar left hemisphere dominance for movement programming and execution. Further, Elliott et al. (1987), utilized a dual task paradigm to confirm this pattern of asymmetry in DS. As expected, speech production interfered more with right hand finger tapping than left, for both the DS and non-handicapped groups. Kinsbourne and Hicks (1978) have suggested the right hand decrement results from proximity between the centers responsible for speech production and movement execution in the left hemisphere. The close proximity results in “cross-talk” between the two centers, resulting in a right hand performance decrement. Based on the findings from manual asymmetry and dichotic listening studies, Elliott et al. (1987) proposed a model of biological dissociation to explain the cerebral laterality in DS. The main feature of the model is the functional dissociation of the centers for speech perception (right hemisphere), and the left hemisphere centers responsible for movement execution (manual and oral). This means that information perceived by the right hemisphere must be transmitted to left hemisphere centers responsible for movement execution. The resulting interhemispheric transmission is believed to degrade the quality of information reaching left hemisphere movement centers. To date, the model has been able to explain the results of several follow-up studies. As predicted by the model, individuals with DS display particular difficulty planning (LeClair & Elliott, 1993) and executing a movement (Elliott, et al., 1990) in response to a verbal signal/command, but not to a visual signal/command. The right hemisphere specialization for speech perception has been further validated using magnetoencepalography to measure the evoked potential differences in the two cerebral hemispheres during a speech perception task (Weeks, Chua, Elliott, Weinberg, Cheyne & Lyons, 1997). This methodology along with dichotic listening research has been able to support that speech perception is a right hemisphere function in the majority of persons with DS.

The present study which measured asymmetry during a speech production task has provided further credence to the model of biological dissociation. Of particular interest was whether mouth asymmetries during a speech production task would differ between the DS and non-handicapped group. The present study found a RMA at the beginning and end of a speech task, for both the non-handicapped and DS group. This finding is consistent with the model of biological dissociation prediction that the left hemisphere is specialized for speech production. Perhaps more interesting is, that despite a smaller mouth opening, the asymmetry was not affected by the movement amplitude. This indicates that mouth asymmetry is not an artifact of movement amplitude, but reflects an innervatory process that enhances right side opening.

A second purpose of this study was to determine if the degree of asymmetry varied from group to group. This hypothesis was based on previous reports that individuals with DS are not lateralized to the same degree as non-handicapped subjects (Elliott & Weeks, 1990). Although manual asymmetry, dichotic listening and visual field studies have found that the degree of lateralization is reduced, the current study found that the lateralization for speech production does not follow a similar pattern. This was assessed by calculating an asymmetry ratio (R-L/R+L) and examining both the signed and absolute value for this ratio. The ratio analysis indicated that the degree of RMA did not differ significantly between the DS and non-handicapped group. This result may indicate that the dominance for speech production is focally represented to the same degree in right handed non-handicapped persons and individuals with DS.

Mouth Asymmetry For Complex Movements

Another research objective was to determine if the complexity of an oral movement influenced the degree of mouth asymmetry. It was expected that movements embedded within a series (either Sequential 3 or Repeated 7) would result in a greater rightward asymmetry than those movements at the beginning of a sequence (e.g., Single, Sequential 1, Repeated 1). This hypothesis was based on the results of Wolf and Goodale (1987) who found that the magnitude of RMA increased for movements embedded in a series. Wolf and Goodale attributed this result to the left hemisphere, and its dominance for controlling more complex movements. From a theoretical framework, Wolf and Goodale suggested that the increased RMA was a result of the number of postural readjustments needed to successfully complete a movement. This explanation was based on Kimura's (1977, 1982) model of postural transitions. According to the model, the left hemisphere possesses a mechanism that allows the smooth transition from one posture to another (Kimura, 1977, 1982; Kimura & Archibald, 1974). Kimura's work was based upon a neurological population comprised of individuals with right and left hemisphere brain damage,[6] which may limit the generalizability of her results. Kimura (1977) found that a task requiring the selection and repetition of a movement pattern did not impair patients with left hemisphere damage. However, a task which necessitated the selection and execution of three unique postures severely affected the performance of left hemisphere damaged patients (Kimura, 1977). Wolf and Goodale employed a loose interpretation of Kimura's postural transition model to explain the increase in RMA for embedded movements found in their study. Embedded movements were believed to increase RMA because of the necessity to switch postures from movement to movement. A stricter interpretation of Kimura's theory would be that sequential movements embedded within a series should result in the largest RMA because this condition actually involved the transition from one posture to another. This was not the case for the Wolf and Goodale study. An enhanced RMA was found for both movements in the embedded sequential and repeated conditions. Wolf and Goodale speculated the similar RMA for embedded sequential and repeated movements reflects the neurological make-up of subjects used in the original Kimura (1977, 1982) studies. Wolf and Goodale hypothesized that a "fine grain" analysis of LHD patients would reveal a depressed function for both movement conditions.

The present investigation did not find an increase in RMA for movements embedded in a series, despite employing a similar methodology to that used in the original study (Wolf & Goodale, 1987). In the present investigation, the seventh phoneme in the Repeated condition was chosen for data analysis rather then the fifth, which was used by Wolf and Goodale. Our rationale for doing so was to further equate the temporal demands in the sequential and repeated conditions. Therefore, in the present study the repeated and embedded movements analyzed were the seventh movement in a series. Perhaps Wolf and Goodale's findings are somehow related to this methodological flaw.

The current results do not support Kimura's model or Wolf and

Goodale's (1987) enhanced RMA for embedded movements. Instead, an alternative theory of complex movement control may better describe the neuromuscular facilitation on the right side of the mouth for complex oral movements. As mentioned previously, a major shortcoming of applying the Kimura model to all populations is that it is based entirely on a clinical population. Instead an alternative theory based on a broader population may more appropriately describe a dominant left hemisphere mechanism for complex movements. The alternative is the model of spatial-temporal coordination. Spatial-temporal regulation of muscular efforts are required for all movement outcomes, either a simple task, or those involving multiple postural goals. Whether oral or manual movements, the spatial-temporal theory provides a convincing theoretical framework to describe how the left hemisphere regulates neuromuscular control for complex movements (Kent & Rosenbek, 1982; Roy, Brown & Hardie, 1993; Square-Storer et al., 1989). In the case of oral verbal movements, the articulators must be placed in the correct spatial location at the beginning of each vocalization, as well, the muscular efforts of the facial muscles must be temporally coordinated. The spatial-temporal theory is capable of explaining the left hemisphere mechanism responsible for organizing and controlling complex oral and manual movements (Roy et al., 1993) The theory provides a link between a similar control mechanism for both manual and oral systems, which has long been hypothesized by some researchers (e.g., De Renzi et al., 1966). The fact that the spatial-temporal theory can explain control for both output systems provides a strong line of evidence to support the existence of a left hemisphere mechanism dominant for this function.

The results of the current study lend further support to the spatial-temporal model because movement conditions did not differ from one another with respect to RMA. Perhaps, the extent of movement programming and the initial articulator placement in the Single, Sequential 1, and Repeated 1 conditions, taxed the left hemisphere to the same degree as the temporal regulation required to coordinate the temporal phasing of muscular efforts in Sequential 3 and Repeated 7 movements. Thus, the asymmetry across all conditions did not change significantly because the spatial requirements for movements at the beginning of a series taxed the left hemisphere to the same degree as temporal regulation in the embedded movements.

Although the validity of this explanation seems plausible an attempt to empirically measure the spatial-temporal demands using the current methodology proved difficult. An analysis of the phonetic nature of the vocal productions used in the experiment may alleviate these methodological concerns. The phoneme “Pi” resulted in the largest L-R difference. An examination of the articulator requirements of this phoneme revealed that this phoneme required the most complex movement pattern when compared to “Ma” and “Ba”. Verbal production of the bilabial phoneme “Pi” involves, the restriction of air flow in the vocal cords. As well, [p] is a stop sound which involves using a set of muscle to close and hold the lips together while a second set opens the lips rapidly at the release of the stop (Luchsinger & Arnold, 1965). Production of [p] also requires coordination between mandible and lip movements (Clark & Yallop, 1990). A strict interpretation of the spatial temporal theory would suggest that the spatial location and coordination of multiple muscles and articulator systems taxes the left hemisphere to a greater extent which may have influenced the degree of asymmetry for the production of the phoneme “Pi”.

Down Syndrome and Complex Movements

An initial hypothesis was that subjects in the DS group would not be lateralized to the same degree as non-handicapped subjects. This assumption was based on Lennenberg’s (1964, 1967) assertion that language and other skills lateralize with development. Since the development of individuals with DS does not progress to the same degree as non-handicapped individuals it was anticipated DS subjects would be less lateralized for the speech production task. However, the pattern of asymmetry in the present study indicated that like non-handicapped subjects, the transition of one movement to another did not affect the degree of mouth asymmetry. Further support for this speculation stems from the pattern of asymmetry during the production of the phoneme “Pi”. The pattern of RMA exhibited by persons with DS was similar to that of the non-handicapped group. An interpretation of this is that individuals with DS have a left hemisphere spatial-temporal mechanism similar to that of non-handicapped individuals. This speculation is based on the fact that individuals with DS displayed the same pattern of greater RMA for the phoneme “Pi” than for the other phonemes. Again, this result has been interpreted to reflect the greater spatial-temporal programming required for the phoneme “Pi”.

Group Differences in Movement Amplitude

The resting mouth size for the DS and non-handicapped group did not differ. In contrast, the final mouth opening for the DS group was significantly smaller than the non-handicapped group. It was anticipated that the resting mouth values and overall amplitude of mouth movement would be greater for the non-handicapped group, based on the anthropometric differences between DS and non-handicapped individuals. Anthropometric measures of individuals with DS clearly indicate that the mouth size of this population is smaller than non-handicapped individuals (Joseph & Dawbarn, 1970). This is consistent in individuals with their genotype (Smith & Berg, 1976), The amplitude of mouth opening in the current study is indicative of typical anthropometric differences, while the resting face values appear to conflict with previous research. This apparent discrepancy can be explained by the methodology used in the current study which may not have been accurate enough to detect resting facial differences. Markers were placed around the perimeter of the lips, since the size of the lip surface for individuals with DS is larger (Smith & Berg, 1976), this factor may have accounted for the equivalence between the DS and non-handicapped group at rest.

Group Differences in Variability

Speech production is a complex motor action requiring the timing and control of several articulators. Despite the articulator variability in speech, non-handicapped subjects are consistently able to deal with the variability in achieving speech production (Gentil, 1982). The present study utilized a within-subject analysis of variability to determine if the final mouth position was more variable for persons with DS. Variability in general has been shown to be a reliable indicator of differences between handicapped and non-handicapped groups. Neuropsychologists have traditionally recognized variability as a cornerstone when making between-group clinical comparisons (e.g., more variability in clinical groups) (Roy et al., 1991). Thus, the results of the present study, indicating that individuals with DS were more variable in terminating the end of a speech movement were not surprising. A well established difference between individuals with and without mental handicaps is slower and more variable movement initiation (Baumeister & Kellas, 1968). These differences exist in several output systems. Davis, Sparrow and Ward (1991) found increased variability for initiating manual movements in participants with DS and a mentally handicapped group when compared to a non-handicapped group, while Henderson, Illingworth and Allen (1991) noted a similar finding for vocal reaction time. As well, individuals with DS and persons with other mental handicaps have been shown to be more variable in completing simple manual movements (Elliott et al., 1986; Elliott, Edwards, Weeks, Lindley & Carnahan, 1987). This same population is also more variable in tasks requiring spatial accuracy (Hodges, Cunningham, Lyons, Kerr & Elliott, 1995). This latter result can be interpreted as impaired ability to terminate a manual movement consistently. This lack of spatial consistency is similar to the present findings which showed an impaired ability to terminate an oral movement. As well, the increased variability for maximum velocity, corresponded to the results of Hodges et al. (1995) who found that handicapped subjects are more variable performing a movement without vision.

Although individuals with DS tend to be more variable than non-handicapped subjects on a wide spectrum of tasks, this pattern of performance does not seem to be syndrome specific. Thus, increased variability is probably not a consequence of DS but rather an attribute associated with a mental handicap (Elliott et al., 1987; Henderson et al, 1991). However, based on our knowledge of the verbal-motor difficulties associated with DS, the model of biological dissociation may shed some light on why DS individuals were more variable in the oral speech task. The model postulates that the dissociation of speech perception and movement execution centers leads to a quantitative reduction in the quality of information reaching the speech production centers. In the present experiment, the instructions given to subjects were similar from trial to trial. The dissociation between speech centers may have resulted in a smaller signal to noise ratio, which limited the ability of speech production centers to receive redundant information from trial to trial. The variable messages being received by speech production centers may lead to increased variability in producing and terminating a speech movement. Increased variability in the DS group coincides with research on apraxic individuals who have been found to demonstrate an increased error rate in speech production. This is believed to be a result of variability in their motor programming (Johns & Darley 1970). Similarly Robin, Bean and Folkins (1989) using a kinematic analysis technique were able to determine that apraxic patients are more variable in reaching maximum velocity of their lower lip. These results coincide with the present kinematic measure of peak velocity, which indicated that the maximum velocity of lip movement in the DS group was more variable than the non-handicapped group. Thus, the variability in both the spatial and temporal aspects of a movement may indicate that the quality of information relayed to the speech production centers in DS is impaired.

Verbal Errors and the Model of Biological Dissociation

Verbal errors made by non-handicapped subjects were less than 1% of the total number of syllables produced, however a high rate of speech errors was indicative of persons with DS. Speech dysfluency, which occurs in about 1% of the general population, has a much higher occurrence in the DS population. Speech dysfluency in persons with DS has demonstrated a surprising relationship with language. Specifically, better language skills have been linked to greater verbal dysfluency (Devenny & Silverman, 1990). Therefore, speech dysfluencies cannot be attributed to a failure in the language system, but is more specific to a motor production deficit. Motor production difficulty has been has been linked to complex sequential motor tasks, such as speech and a grooved peg board task (Devenny, Silverman, Balgley, Wall & Sidtis, 1990). Devenny and colleagues' have speculated that speech dysfluency results from a breakdown of the neural organization of the complex nature of speech at the consonant vowel level. This assertion explains the high proportion of substitution errors that occurred in the present study. Substitution errors involved the intrusion of a vowel that preceded or followed the target consonant. The mispronunciation and pausing errors in the present study are probably associated with low cognitive functioning and poor verbal comprehension of individuals with DS.

The high proportion of verbal errors committed by individuals with DS is consistent with Devenny and colleagues' assertion that speech dysfluency is a breakdown at the level of neural organization. The results of the current study are consistent with this theory; as well, the results are generalizable to the model of biological dissociation. A review of the speech error patterns for aphasic and apraxic individuals indicated that the pattern of errors committed by individuals with DS are similar to aphasic individuals. Specifically, the high proportion of sound substitution errors is consistent with errors in linguistic processing. In contrast, errors made by individuals with apraxia of speech are more variable, with the locus of error likely to change from trial to trial (see Square et al., 1997, for review). Thus, the nature of the verbal errors committed by individuals with DS in the present study is consistent with errors made by LHD aphasic persons. Although these results are suggestive of an impairment at the linguistic processing level, it is doubtful that the errors were a result of a linguistic or phonological impairment. The mental age of participants with DS used in the present study was 7.3 years, thus the verbal errors are not likely attributed to a linguistic impairment, due to the simplicity of the task used in the current investigation. Instead, the model of biological dissociation may provide a better framework to explain the errors due to the global nature of organic brain damage associated with DS. Specifically, the nature of the verbal errors may be indicative of 'corrupted' information reaching the movement executive system in the left hemisphere. Thus, the high proportion of substitution errors could be directly attributable to the verbal nature of the instructions. In the case of persons with DS, substitution errors may have resulted due to the interhemispheric transmission of information perceived in the right hemisphere to movement execution centers in the left hemisphere. This interhemispheric transmission may have resulted in the same quantity of information reaching the speech production centers, but a reduced quality of information, thus accounting for the substitution errors. Future studies may be better able to elucidate this speculation by examining the relationship between individual dichotic listening scores and verbal errors. Perhaps individuals who have speech perception centers lateralized to the left hemisphere would exhibit a reduced number of errors.

Conclusion

Past research has shown that the mouth asymmetry methodology is a reliable indicator of the cerebral specialization for speech and language (Caldabert et al, 1994; Graves et al., 1982; Graves et al., 1985; Wolf & Goodale, 1987). In the present study this methodology was employed to determine if speech production for individuals with DS was lateralized to a cerebral hemisphere. The results indicated that like non-handicapped subjects, participants with DS demonstrated a RMA for the production of speech. This RMA is consistent with our knowledge of cerebral organization and the dominant role played by the left hemisphere for speech and language.

Contrary to the initial hypothesis, the extent of a RMA did not change as the complexity of a verbal movement increased (cf. Wolf & Goodale). This contradiction has been interpreted to reflect slight methodological differences between Wolf and Goodale's study and the present investigation. As well, the spatial-temporal theory (Kent & Rosenbek, 1982; Roy et al., 1989) may prove to be a more appropriate theoretical framework to describe the similar asymmetry findings across the various movement conditions.

Terminating a verbal movement was more variable for individuals with DS. This is consistent with previous reports indicating that manual and vocal movements are more variable in this population (Elliott, 1985; Henderson et al., 1991). As well, a large proportion of syllables produced by individuals with DS were errorful, which has been interpreted to reflect a faulty perceptual mechanism. Analysis of mouth asymmetry, movement variability and verbal errors are consistent with the predictions of the model of biological dissociation (Elliott et al., 1987). The present investigation has shown that speech production in persons with DS is lateralized to left hemisphere, while Elliott et al. (1994) have shown that speech perception is lateralized to right cerebral hemisphere. Therefore, interhemispheric transmission of verbal information may result in a degradation of the quality of information reaching left hemisphere speech production centers resulting in movement variabiity and speech errors.

Further studies are required to determine if a similar pattern of asymmetry is indicative of individuals who are left handed (non-handicapped and DS). As well, a follow-up study examining the mouth asymmetry for non-verbal oral movements in persons with DS would further our understanding of the neural mechanims which underlie the motor control process for oral-facial movements in this population.

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Author Notes

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Footnotes

1 A demonstration of hand preference was used to classify handedness for individuals with Down syndrome because it was crucial that participants were right handed.

2. The sequential syllable condition included three sets of syllable strings. The strings used were “Ma Ba Pi”, “Ba Pi Ma and “Pi Ma Ba”.

3. The error notation system was adapted from the error notation system used by Square, Qualizza & Roy, 1989.

4 The direction of asymmetry reflects which side of the mouth exhibits a preference or performance advantage and is a dichotomous measure. The degree of asymmetry represents the extent to which one side of the mouth is opened relative to the other.

5. Two participants in the Down syndrome group were excluded from the assessment of verbal error due to a loss of data.

6. The individuals used in Kimura (1977, 1982) studies included 153 persons with brain injuries, 101 of these patients had damage localized to the left hemisphere. The majority of patients had suffered a unilateral cerebral vascular accident.

Table 1.

Subject Characteristics

Group	Gender	Chronological Age (years)		Mental age (years)		Handedness
		Mean	SD	Mean	SD	
Non-handicapped	6F, 4M	23.25	7.04	----	----	10 Right
Down syndrome	6F, 4M	22.73	7.07	7.42	2.45	10 Right

Table 2

Intra-Class Reliability Coefficients for Intra Experimenter Digitizing Reliability

Marker Reference Number	Axial Coordinate	Intra-class Reliability Coefficient
2	y	0.91
3	y	0.99
4	y	0.96
5	y	0.79
6	y	0.80
7	y	0.79
9	x	0.76
10	x	0.84

Table 3.

Movement Conditions

Condition	Speech Task
Single	“Ma”
Sequential 1	“Ma Ba Pi, Ma Ba Pi, Ma Ba Pi..........
Sequential 3	“Ma Ba Pi, Ma Ba Pi, Ma Ba Pi..........
Repeated 1	“Ma Ma Ma Ma Ma Ma Ma Ma..... .....
Repeated 7	“Ma Ma Ma Ma Ma Ma Ma Ma..........

Note. The underlined movements were those used in data analysis. The measures for Sequential and Repeated conditions were taken on each trial.

Table 4.

Proportion of Verbal Errors and Error Type

Substitution	Mispronounced	Pausing	Repetition	Timing
.46	0.29	0.19	0.05	0.01

Note: The verbal errors were classified only for the Down syndrome group. Each syllable within the syllable string was analyzed.

Figure Captions

Figure 1. Schematic diagram of reference markers used as digitizing reference points.

Figure 2. Mean maximum vertical displacement and standard error as a function of group.

Figure 3. Mean maximum vertical displacement and standard error as a function of movement condition.

Figure 4. Mean vertical total marker movement and standard error as a function of side and phoneme.

Figure 5. Mean maximum vertical velocity and standard error as a function of phoneme.

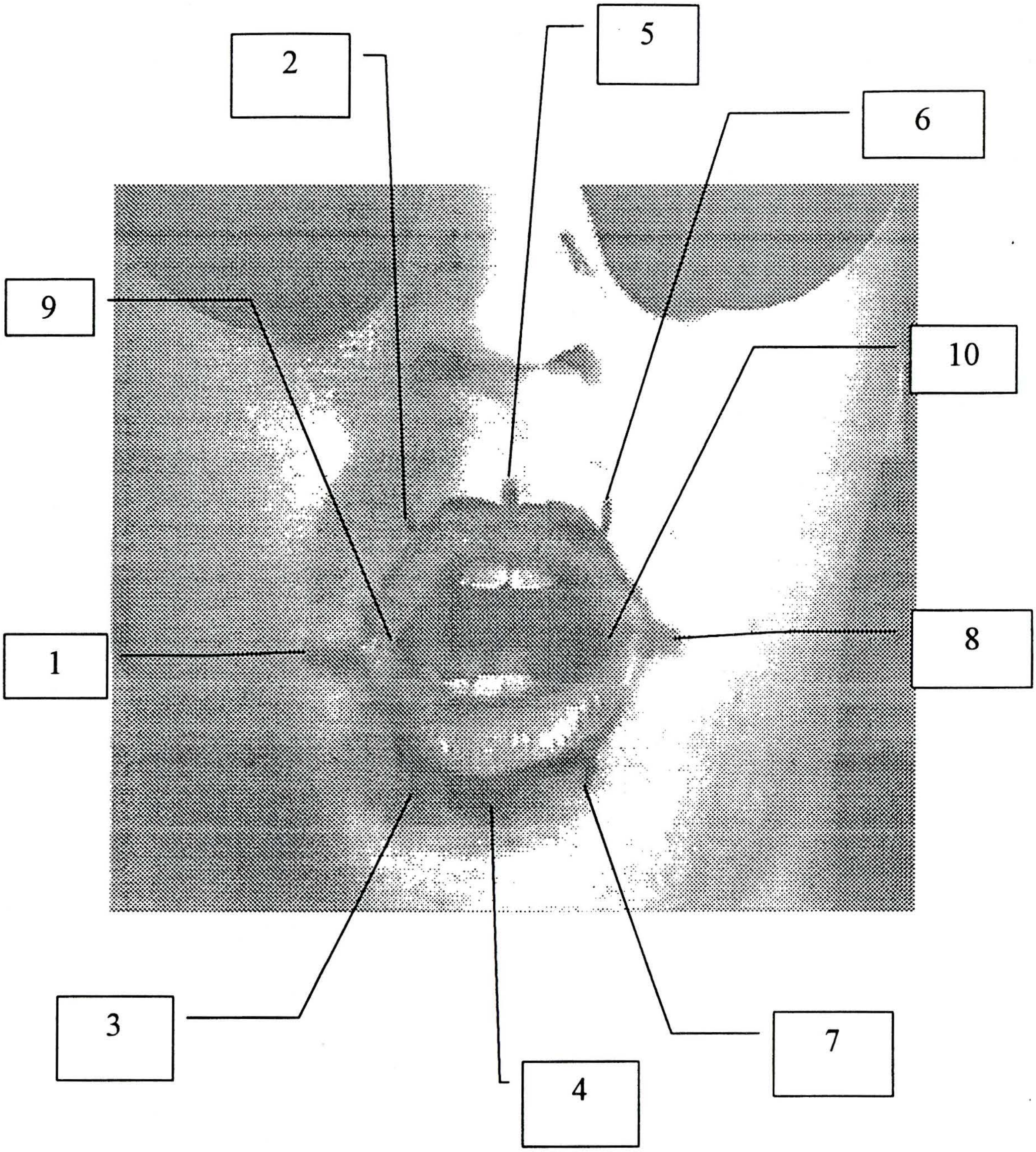
Figure 6. Mean maximum vertical velocity and standard error as a function of side and phoneme.

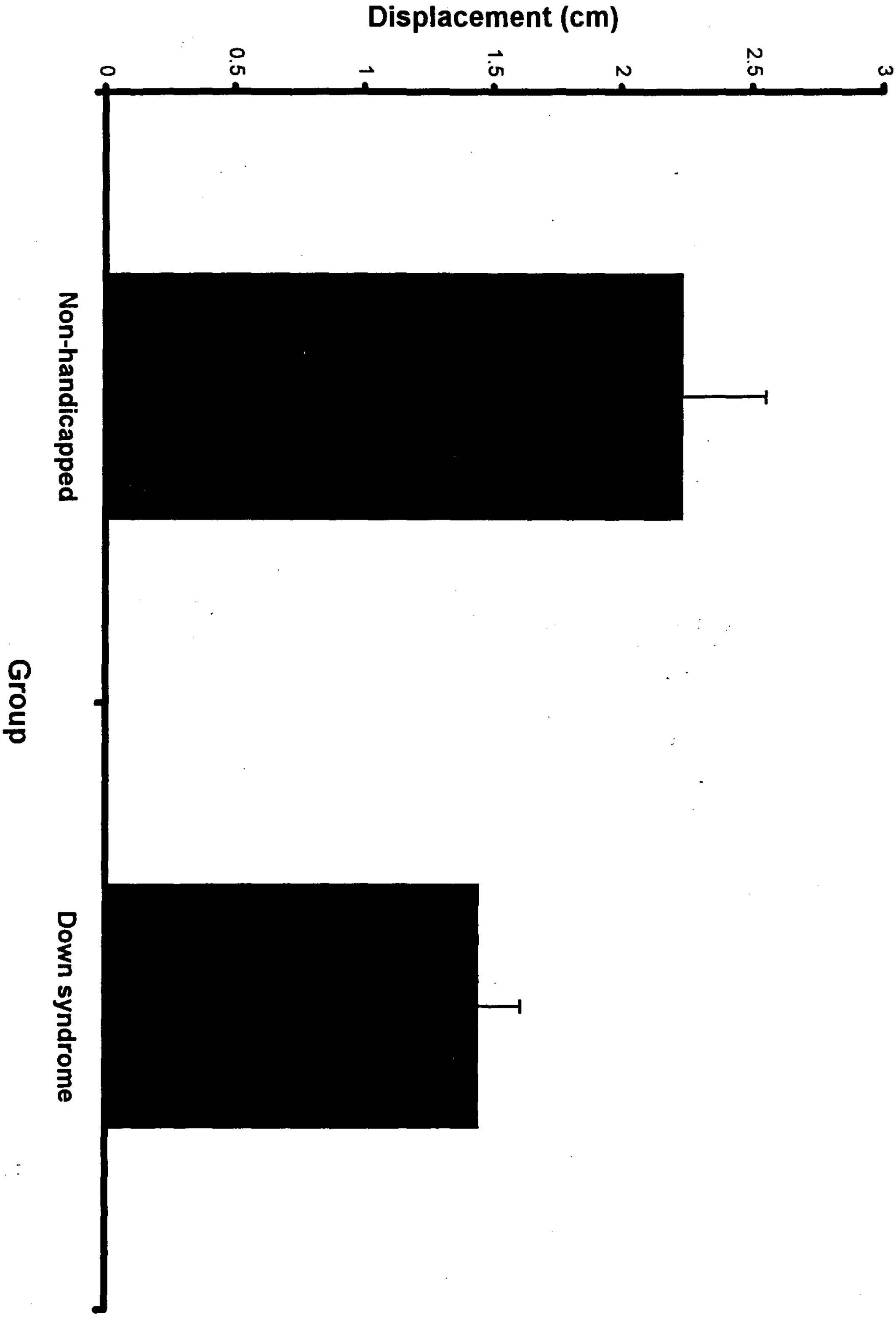
Figure 7. Mean initial horizontal aperture and standard error as a function of side.

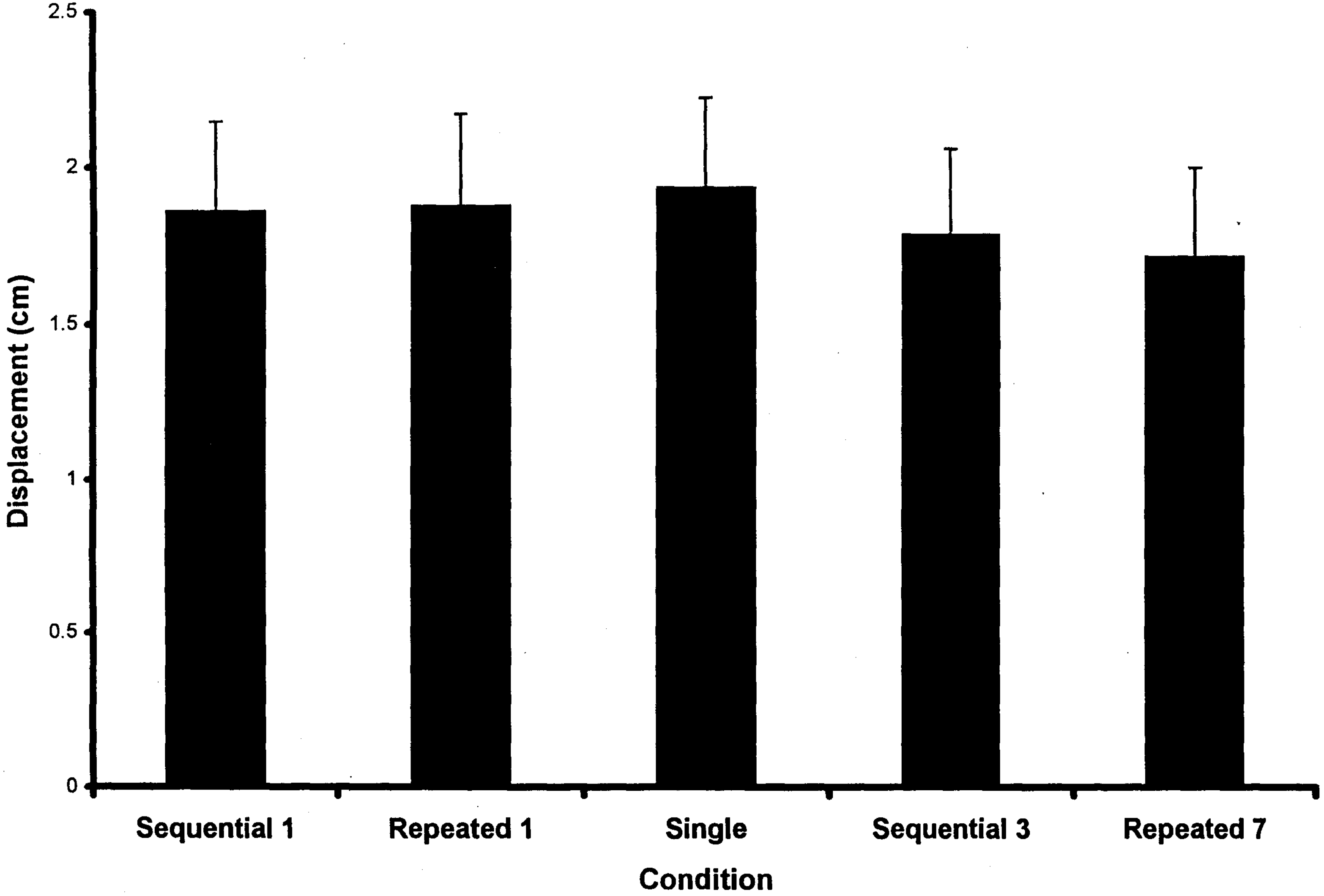
Figure 8. Mean maximum horizontal aperture and standard error as a function of side.

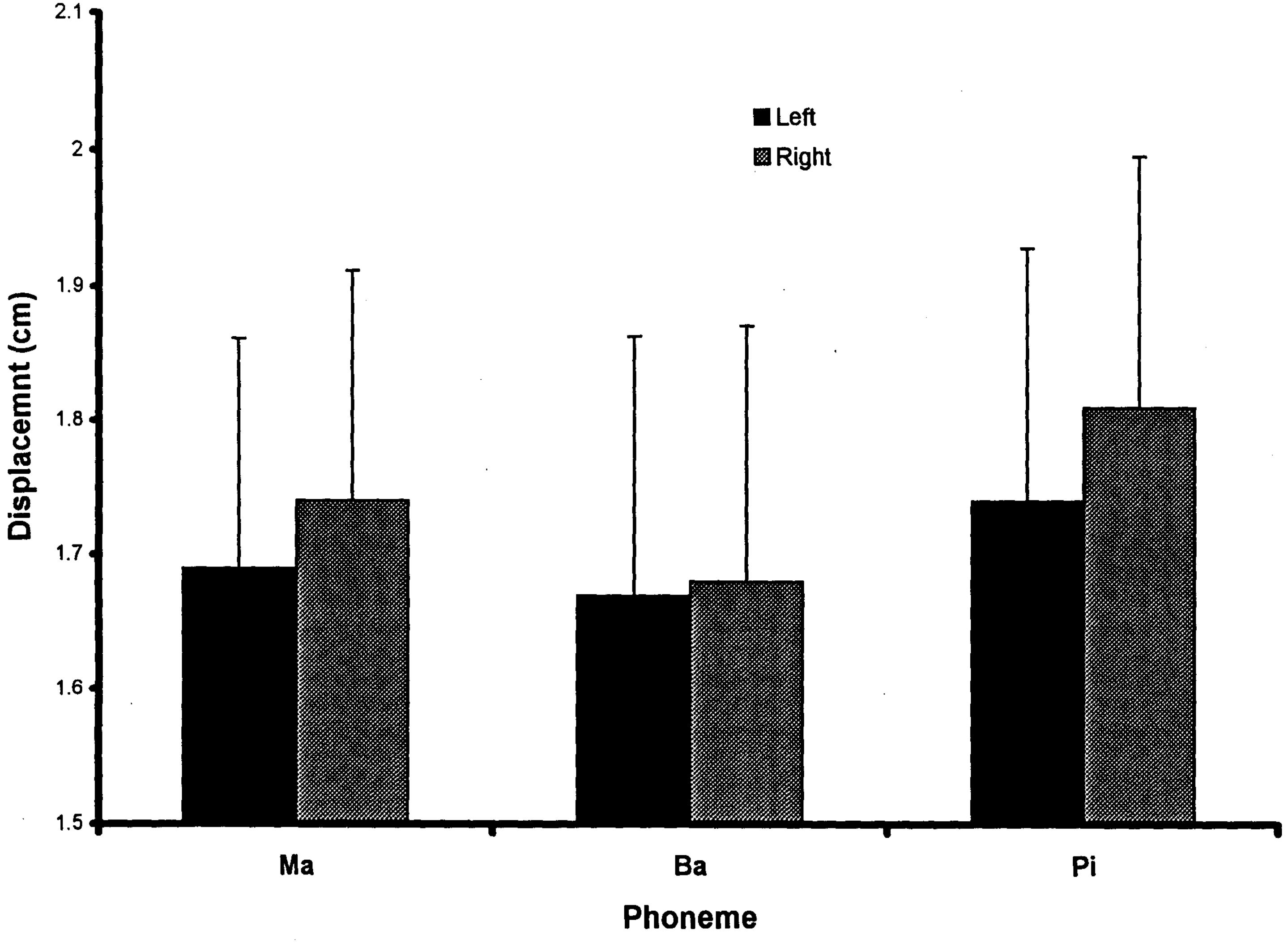
Figure 9. Mean within-subject standard deviation for maximum horizontal aperture and standard error as a function of group.

<u>Figure 10</u>. Mean within-subject standard deviation for maximum horizontal aperture and standard error as a function of group and side.


2
5
6
9
10
1
8
3
4
7


Displacement (cm)
0
0.5
1
1.5
2
2.5
3
Non-handicapped
Down syndrome
Group


2.5
2
1.5
1
0.5
0
Displacement (cm)
Sequential 1
Repeated 1
Single
Sequential 3
Repeated 7
Condition


Displacemnt (cm)
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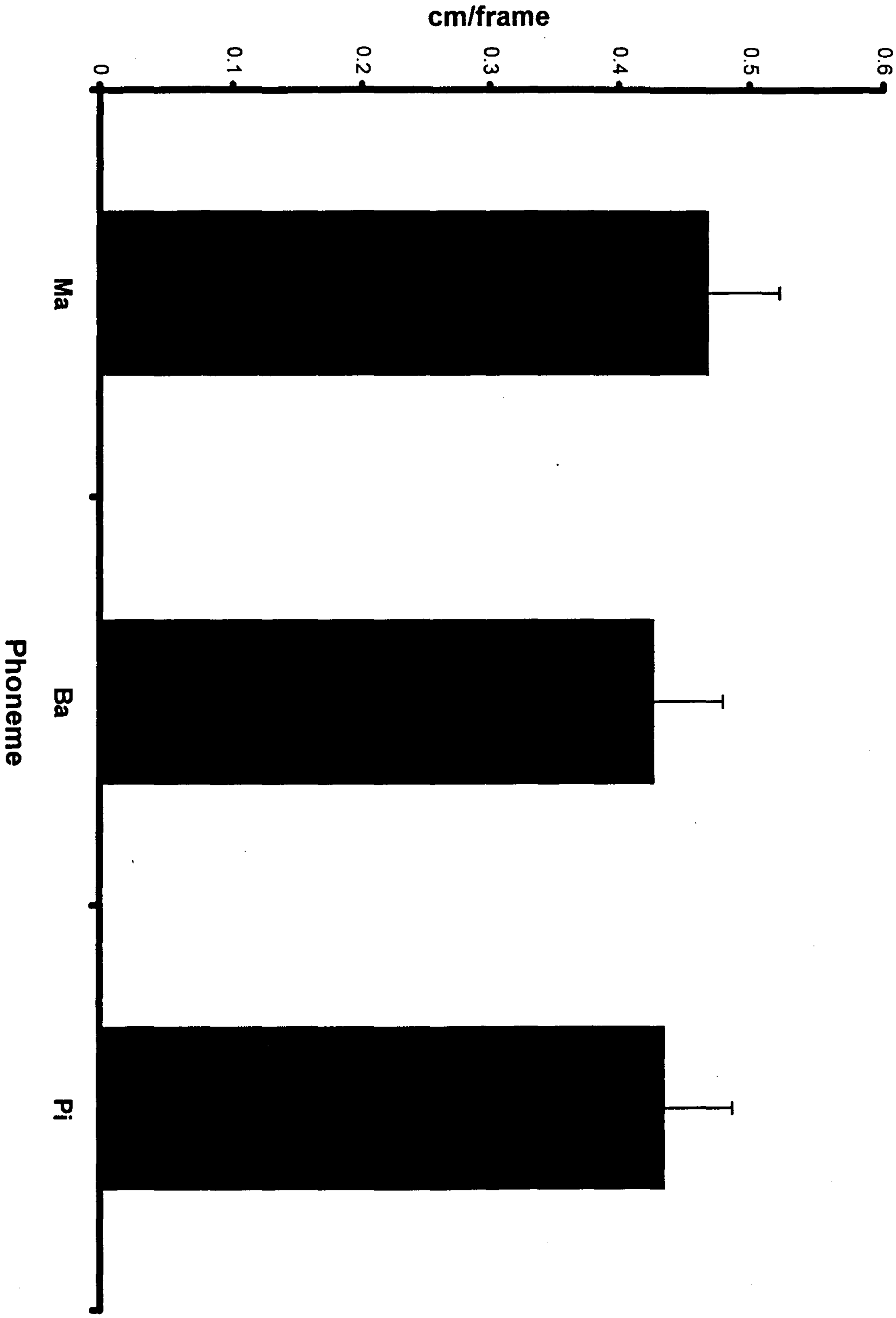
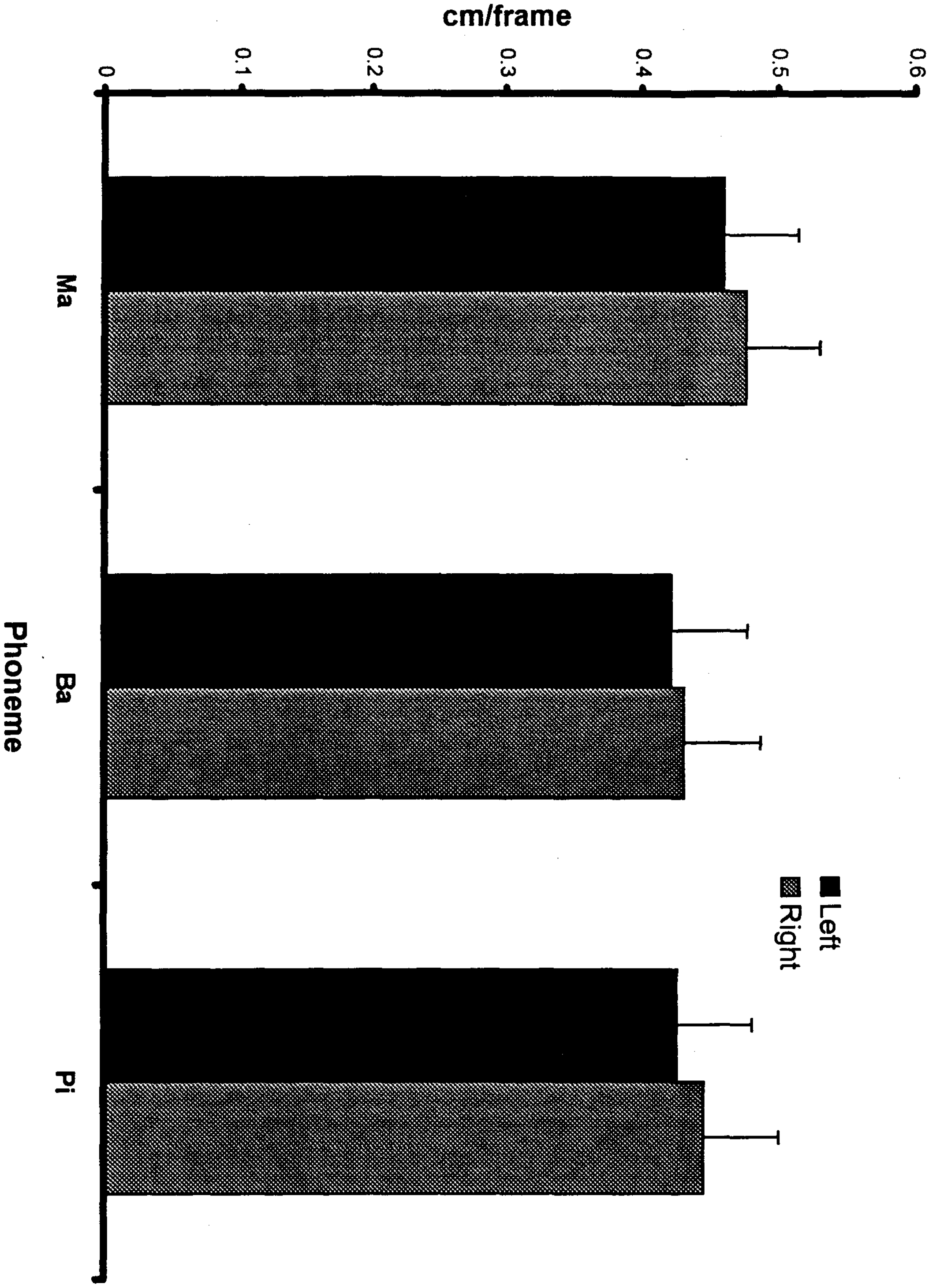
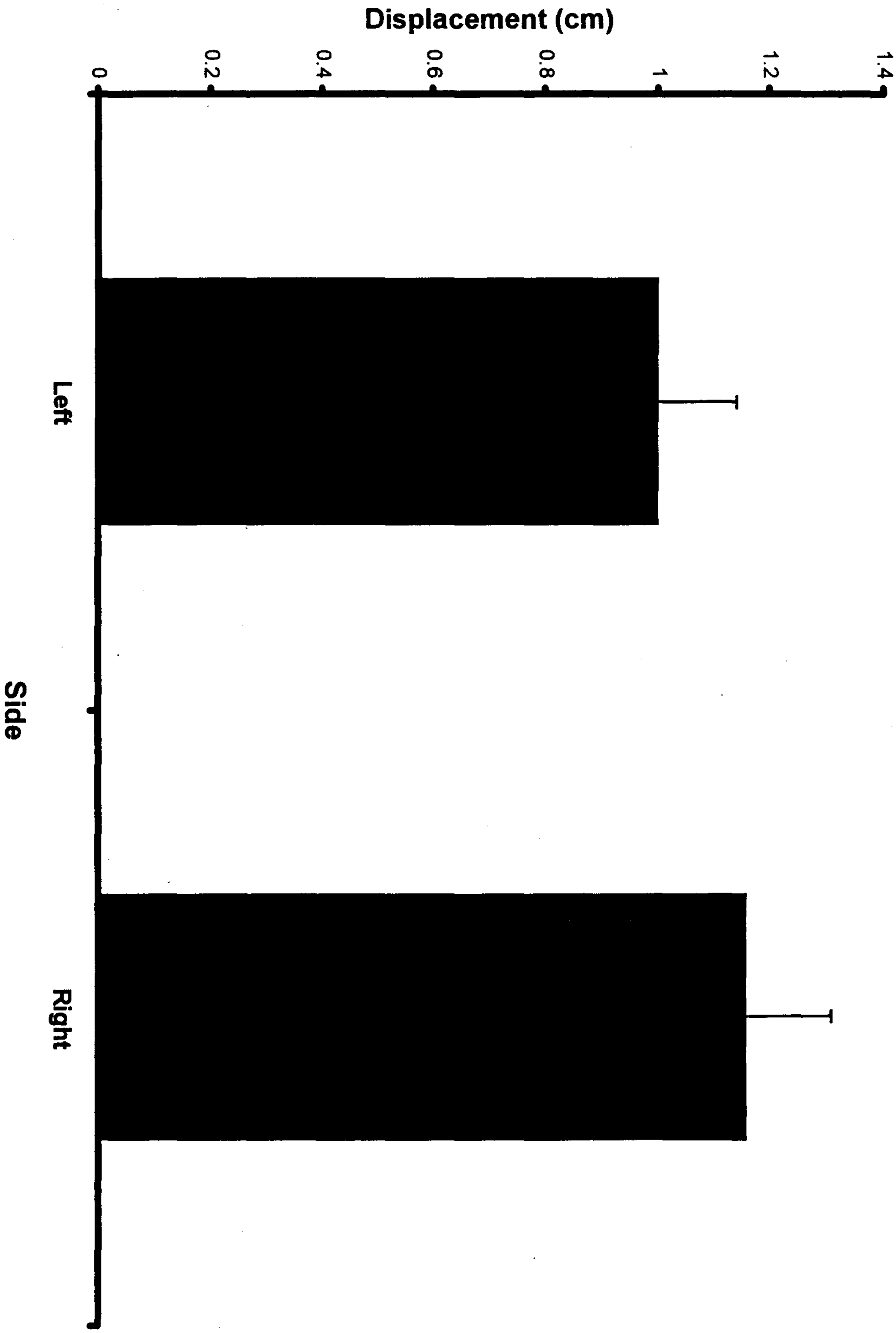
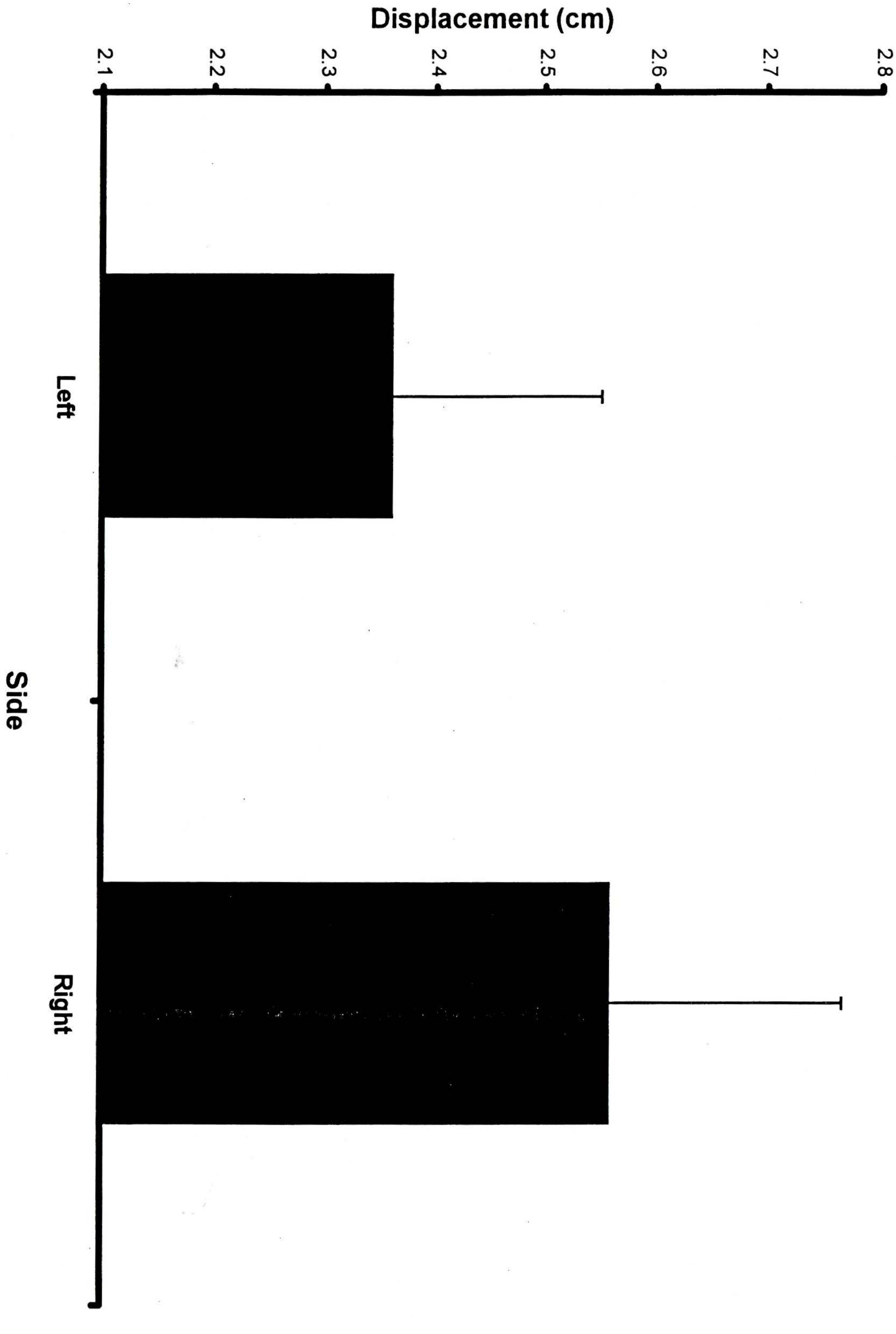
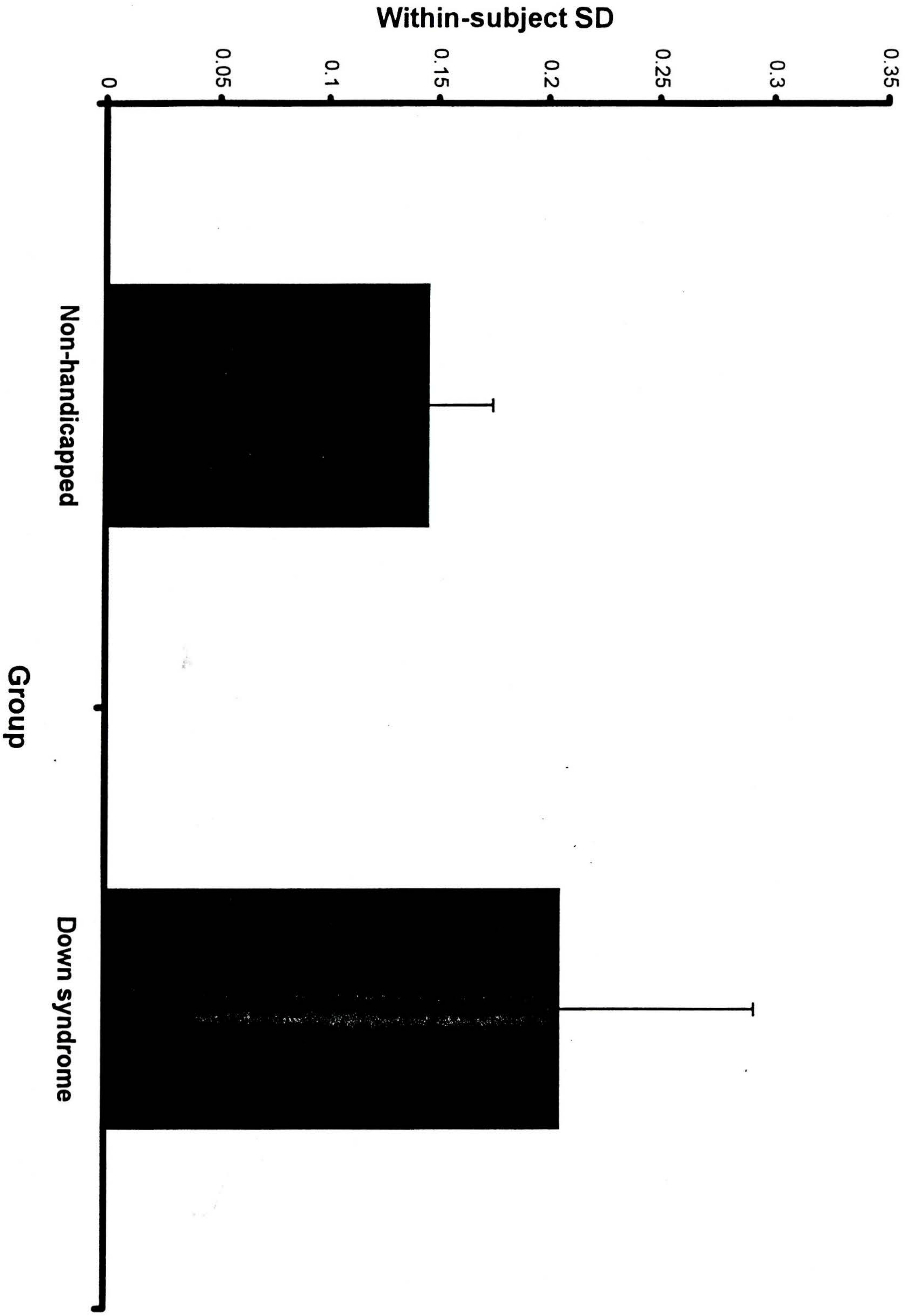
2
1.9
1.8
1.7
1.6
1.5
■ Left
▨ Right
Ma
Ba
Pi
Phoneme

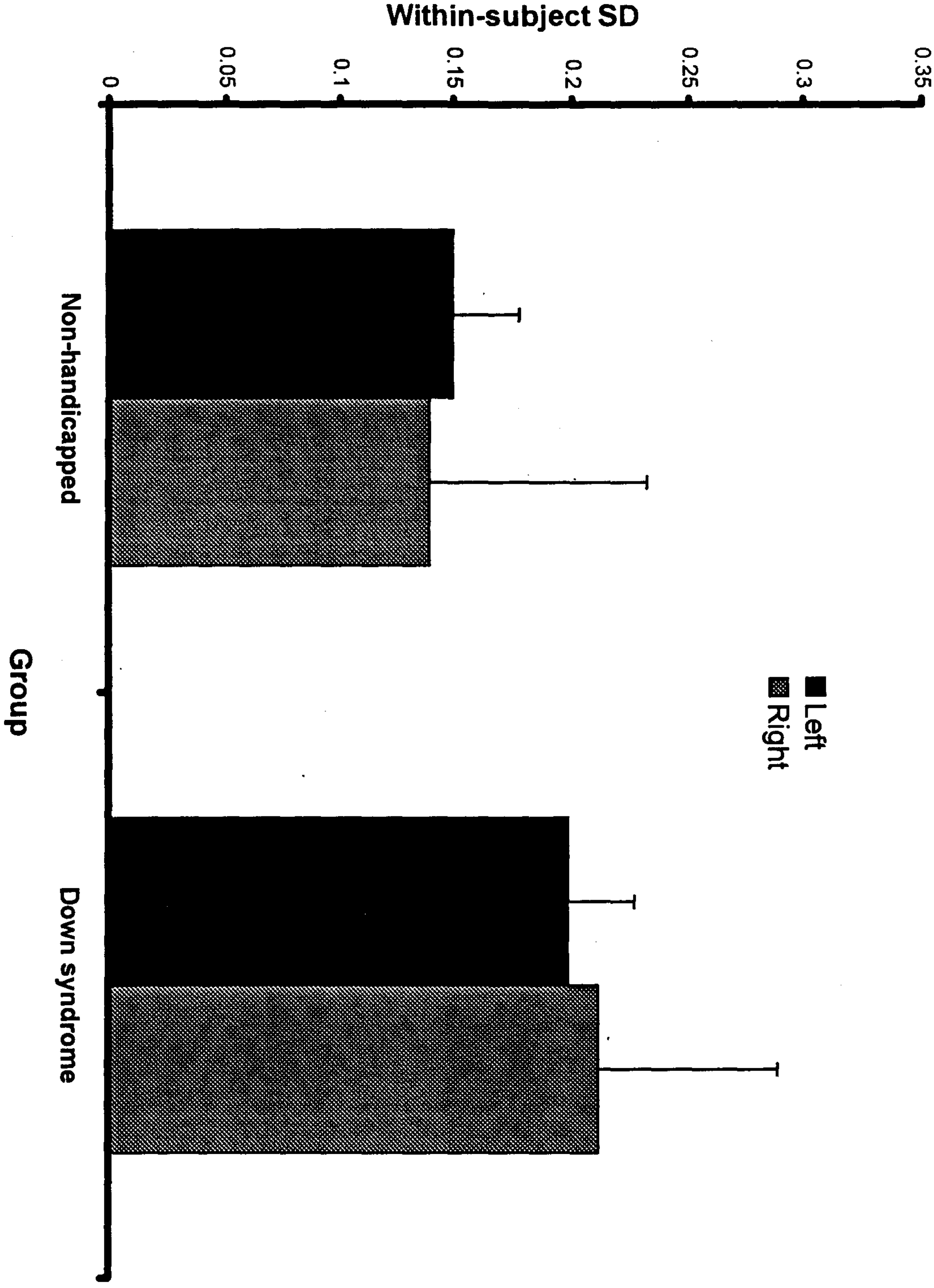

cm/frame
0
0.1
0.2
0.3
0.4
0.5
0.6
Ma
Ba
Pi
Phoneme


cm/frame
0
0.1
0.2
0.3
0.4
0.5
0.6
Ma
Ba
Pi
Phoneme
■ Left
▨ Right


Displacement (cm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Left
Right
Side


Displacement (cm)
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
Left
Right
Side


Within-subject SD
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Non-handicapped
Down syndrome
Group


Within-subject SD
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Left
Right
Non-handicapped
Down syndrome
Group

Appendix A

Verbal Error Notation System

1. Correct Production

A verbal task was considered correct if all three syllables within the syllable string were pronounced correctly and at a rate of one string per 2.5 seconds.

2. Syllable Error

Repetition - Cases in which the entire target syllable was replaced by the syllable immediately preceding the target syllable.

Omission - No response was given.

3. Mispronunciation - Cases in which an extraneous consonant was added to the end of a syllable.

4. Substitution Error - Partial aspects of a previously performed or to be performed syllable were performed in conjunction with partial aspects of the target syllable.

5. Timing Error

Timing Long - The completion time of a syllable was considered errorful if the duration of initiation to syllable competition was longer in duration than normal.

Timing Short - The completion time of a syllable was considered errorful if the duration of initiation to syllable completion was shorter in duration than normal.

6. Pausing Error

An error was recorded in cases where a pause before an attempt to initiate verbal production occurred. This pause followed the initiation command given by the experimenter.

Appendix B

Table 5.

Mean Initial Horizontal Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	1.14	0.98	0.95	1.34	1.13	1.16
repeated 1	1.11	1.06	1.00	1.25	1.23	1.23
single	1.10	1.04	1.07	1.25	1.25	1.26
sequential 3	1.17	1.18	1.17	1.32	1.36	1.35
repeated 7	1.17	1.14	1.02	1.34	1.35	1.28
Down syndrome						
sequential 1	0.89	0.92	0.97	0.96	1.13	1.05
repeated 1	0.91	0.89	0.84	1.06	1.00	1.02
single	0.94	0.88	0.97	1.14	1.04	1.11
sequential 3	0.84	0.91	0.94	0.93	1.07	1.09
repeated 7	0.98	0.89	0.91	1.01	1.01	1.07

Table 6.

Mean Initial Vertical Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.91	0.78	0.76	1.03	0.89	0.85
repeated 1	0.87	0.80	0.77	0.94	0.94	0.87
single	0.69	0.63	0.60	0.71	0.69	0.65
sequential 3	0.82	0.76	0.79	0.94	0.87	0.88
repeated 7	0.79	0.76	0.69	0.87	0.91	0.79
Down syndrome						
sequential 1	0.50	0.48	0.50	0.50	0.49	0.48
repeated 1	0.54	0.49	0.42	0.57	0.47	0.45
single	0.54	0.41	0.44	0.59	0.44	0.44
sequential 3	0.57	0.65	0.64	0.56	0.63	0.68
repeated 7	0.57	0.48	0.57	0.59	0.52	0.63

Table 7.

Mean Maximum Horizontal Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	2.65	2.53	2.76	2.82	2.70	2.95
repeated 1	2.65	2.69	2.78	2.82	2.86	2.91
single	2.59	2.71	2.83	2.74	2.89	2.99
sequential 3	2.63	2.49	2.76	2.78	2.69	2.93
repeated 7	2.61	2.62	2.67	2.79	2.79	2.84
Down syndrome						
sequential 1	2.00	2.07	2.17	2.25	2.19	2.40
repeated 1	2.11	1.92	2.06	2.35	2.19	2.34
single	2.26	1.94	2.17	2.56	2.19	2.41
sequential 3	2.00	2.06	2.08	2.23	2.18	2.34
repeated 7	2.12	1.83	2.04	2.34	2.10	2.27

Table 8.

Mean Maximum Vertical Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	2.22	2.16	2.26	2.35	2.23	2.39
repeated 1	2.21	2.30	2.26	2.30	2.42	2.37
single	2.24	2.30	2.34	2.37	2.41	2.49
sequential 3	2.11	2.05	2.18	2.24	2.10	2.31
repeated 7	2.01	2.06	2.00	2.13	2.18	2.14
Down syndrome						
sequential 1	1.44	1.41	1.52	1.43	1.44	1.54
repeated 1	1.60	1.31	1.41	1.68	1.30	1.46
single	1.67	1.36	1.48	1.73	1.38	1.51
sequential 3	1.31	1.44	1.42	1.43	1.46	1.50
repeated 7	1.47	1.20	1.48	1.42	1.14	1.44

Table 9.

Mean Maximum Horizontal Velocity (cm/frame) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	1.73	1.56	1.66	1.75	1.73	1.75
repeated 1	1.80	1.67	1.63	1.77	1.81	1.79
single	1.74	1.67	1.77	1.81	1.81	1.86
sequential 3	1.68	1.65	1.68	1.73	1.73	1.78
repeated 7	1.78	1.65	1.55	1.80	1.79	1.73
Down syndrome						
sequential 1	1.88	1.90	1.91	1.93	2.07	1.96
repeated 1	1.69	1.82	1.91	1.95	1.90	1.91
single	1.82	1.77	1.95	2.01	1.88	2.18
sequential 3	1.80	1.87	1.85	1.84	1.95	1.98
repeated 7	1.70	1.96	1.92	1.89	1.97	1.97

Table 10.

Mean Maximum Vertical Velocity (cm/frame) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.49	0.43	0.43	0.52	0.44	0.48
repeated 1	0.49	0.46	0.44	0.52	0.49	0.48
single	0.52	0.51	0.49	0.55	0.55	0.51
sequential 3	0.46	0.41	0.43	0.49	0.41	0.46
repeated 7	0.48	0.40	0.40	0.49	0.42	0.42
	0.42	0.41	0.44	0.49	0.43	0.43
Down syndrome						
sequential 1						
repeated 1	0.41	0.41	0.42	0.42	0.41	0.44
single	0.45	0.39	0.43	0.45	0.40	0.42
sequential 3	0.46	0.45	0.42	0.47	0.45	0.44
repeated 7	0.43	0.42	0.41	0.44	0.42	0.41
	0.42	0.36	0.40	0.43	0.34	0.40

Table 11.

Mean Horizontal Total Marker Movement (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	3.36	3.32	3.44	3.56	3.58	3.68
repeated 1	3.46	3.36	3.42	3.64	3.66	3.71
single	3.26	3.40	3.49	3.51	3.68	3.71
sequential 3	3.33	3.26	3.48	3.67	3.49	3.66
repeated 7	3.44	3.31	3.37	3.71	3.57	3.64
Down syndrome						
sequential 1	3.42	3.34	3.54	3.46	3.50	3.76
repeated 1	3.33	3.33	3.55	3.52	3.51	3.66
single	3.52	3.31	3.57	3.76	3.46	3.77
sequential 3	3.40	3.38	3.52	3.48	3.42	3.68
repeated 7	3.26	3.21	3.41	3.43	3.41	3.54

Table 12.

Mean Vertical Total Marker Movement (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	1.68	1.73	1.78	1.76	1.75	1.92
repeated 1	1.69	1.78	1.71	1.72	1.86	1.81
single	1.97	2.12	2.05	2.07	2.19	2.13
sequential 3	1.56	1.63	1.73	1.66	1.58	1.85
repeated 7	1.60	1.54	1.56	1.64	1.59	1.65
Down syndrome						
sequential 1	1.68	1.62	1.78	1.68	1.62	1.83
repeated 1	1.72	1.62	1.79	1.83	1.76	1.60
single	1.81	1.78	1.77	1.79	1.81	1.77
sequential 3	1.72	1.58	1.69	1.78	1.72	1.59
repeated 7	1.56	1.37	1.60	1.73	1.58	1.33

Table 13.

Mean Within-Subject Standard Deviation for Initial Horizontal Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.39	0.29	0.34	0.33	0.31	0.36
repeated 1	0.39	0.28	0.30	0.36	0.31	0.33
single	0.33	0.35	0.35	0.37	0.38	0.33
sequential 3	0.31	0.25	0.24	0.31	0.24	0.26
repeated 7	0.29	0.29	0.27	0.29	0.26	0.25
Down syndrome						
sequential 1	0.33	0.36	0.37	0.36	0.38	0.37
repeated 1	0.34	0.39	0.28	0.41	0.33	0.32
single	0.41	0.29	0.35	0.39	0.27	0.35
sequential 3	0.26	0.35	0.40	0.29	0.30	0.38
repeated 7	0.55	0.41	0.34	0.43	0.38	0.33

Table 14.

Mean Within-Subject Standard Deviation for Initial Vertical Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.21	0.14	0.16	0.22	0.14	0.18
repeated 1	0.25	0.18	0.17	0.25	0.18	0.19
single	0.22	0.18	0.19	0.21	0.19	0.18
sequential 3	0.15	0.15	0.15	0.16	0.14	0.14
repeated 7	0.18	0.16	0.14	0.17	0.16	0.14
Down syndrome						
sequential 1	0.17	0.21	0.21	0.19	0.19	0.21
repeated 1	0.19	0.17	0.16	0.19	0.17	0.18
single	0.19	0.13	0.15	0.20	0.14	0.19
sequential 3	0.16	0.18	0.20	0.16	0.18	0.17
repeated 7	0.23	0.30	0.17	0.23	0.19	0.17

Table 15.

Mean Within-Subject Standard Deviation for Maximum Horizontal Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.20	0.13	0.16	0.18	0.12	0.14
repeated 1	0.14	0.12	0.16	0.13	0.11	0.14
single	0.13	0.16	0.23	0.12	0.15	0.25
sequential 3	0.14	0.12	0.14	0.14	0.11	0.13
repeated 7	0.14	0.13	0.15	0.13	0.14	0.13
Down syndrome						
sequential 1	0.14	0.19	0.21	0.17	0.21	0.22
repeated 1	0.21	0.18	0.16	0.22	0.22	0.19
single	0.17	0.16	0.20	0.16	0.16	0.19
sequential 3	0.16	0.19	0.16	0.19	0.22	0.18
repeated 7	0.52	0.18	0.17	0.47	0.19	0.20

Table 16.

Mean Within-Subject Standard Deviation for Maximum Vertical Aperture (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.28	0.20	0.25	0.28	0.19	0.24
repeated 1	0.21	0.20	0.22	0.20	0.19	0.23
single	0.22	0.24	0.23	0.22	0.25	0.20
sequential 3	0.20	0.20	0.22	0.22	0.19	0.22
repeated 7	0.20	0.22	0.22	0.20	0.21	0.21
Down syndrome						
sequential 1	0.21	0.29	0.27	0.22	0.28	0.27
repeated 1	0.26	0.24	0.23	0.25	0.23	0.25
single	0.22	0.19	0.23	0.22	0.19	0.25
sequential 3	0.21	0.24	0.23	0.20	0.24	0.23
repeated 7	0.51	0.20	0.21	0.29	0.23	0.19

Table 17.

Mean Within-Subject Standard Deviation for Maximum Horizontal Velocity (cm/frame) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.29	0.35	0.31	0.34	0.33	0.32
repeated 1	0.36	0.29	0.30	0.30	0.36	0.31
single	0.31	0.32	0.27	0.27	0.36	0.30
sequential 3	0.30	0.30	0.28	0.30	0.27	0.31
repeated 7	0.33	0.31	0.27	0.33	0.32	0.33
Down syndrome						
sequential 1	0.42	0.42	0.42	0.36	0.40	0.38
repeated 1	0.39	0.40	0.39	0.37	0.39	0.33
single	0.39	0.35	0.43	0.39	0.35	0.34
sequential 3	0.36	0.47	0.49	0.32	0.34	0.38
repeated 7	0.40	0.43	0.44	0.32	0.33	0.42

Table 18.

Mean Within-Subject Standard Deviation for Maximum Vertical Velocity (cm/frame) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.08	0.09	0.08	0.10	0.09	0.09
repeated 1	0.08	0.09	0.09	0.09	0.10	0.10
single	0.10	0.09	0.08	0.09	0.10	0.08
sequential 3	0.08	0.08	0.10	0.10	0.08	0.08
repeated 7	0.09	0.07	0.08	0.10	0.08	0.08
Down syndrome						
sequential 1	0.09	0.09	0.11	0.09	0.11	0.11
repeated 1	0.11	0.11	0.14	0.11	0.11	0.14
single	0.13	0.10	0.13	0.14	0.11	0.13
sequential 3	0.11	0.15	0.11	0.12	0.15	0.11
repeated 7	0.13	0.12	0.13	0.11	0.11	0.12

Table 19.

Mean Within-Subject Standard Deviation for Horizontal Total Marker Movement (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.30	0.41	0.26	0.31	0.34	0.26
repeated 1	0.30	0.31	0.32	0.27	0.26	0.27
single	0.26	0.27	0.29	0.25	0.25	0.30
sequential 3	0.24	0.31	0.37	0.25	0.30	0.34
repeated 7	0.29	0.26	0.28	0.27	0.25	0.27
Down syndrome						
sequential 1	0.39	0.39	0.41	0.38	0.47	0.44
repeated 1	0.40	0.41	0.40	0.40	0.45	0.39
single	0.39	0.37	0.47	0.44	0.34	0.49
sequential 3	0.34	0.51	0.37	0.36	0.40	0.37
repeated 7	0.42	0.43	0.40	0.37	0.36	0.41

Table 20.

Mean Within-Subject Standard Deviation for Vertical Total Marker Movement (cm) as a Function of Group, Side, Context and Phoneme

	left			right		
	ma	ba	pi	ma	ba	pi
Non- handicapped						
sequential 1	0.34	0.39	0.30	0.35	0.36	0.32
repeated 1	0.35	0.30	0.33	0.34	0.33	0.35
single	0.35	0.31	0.29	0.33	0.35	0.34
sequential 3	0.28	0.31	0.39	0.28	0.32	0.39
repeated 7	0.33	0.31	0.28	0.30	0.31	0.28
Down syndrome						
sequential 1	0.35	0.40	0.47	0.36	0.40	0.43
repeated 1	0.35	0.42	0.44	0.37	0.40	0.42
single	0.42	0.39	0.38	0.41	0.40	0.40
sequential 3	0.39	0.40	0.40	0.39	0.40	0.38
repeated 7	0.43	0.64	0.39	0.41	0.63	0.39