VERBAL-MOTOR BEHAVIOUR IN ADULTS WITH AND WITHOUT DOWN SYNDROME

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By

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A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

McMaster University

MASTER OF SCIENCE (1999)
(Human Biodynamics)

McMaster University
Hamilton, Ontario

TITLE: Verbal-Motor Behaviour in Adults with and without Down Syndrome

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NUMBER OF PAGES: vi, 108

Foreword

This thesis has been written in a format suitable for publication. Each section of the thesis contains a different experiment that is being submitted separately. The title of the paper in Section I is: "The Processing Speed of Visual and Verbal Movement Stimuli by Adults with and without Down Syndrome. Section II contains a paper titled: "Gender Differences in a Dichotic Listening and Movement Task: Lateralization or Strategy?". The final section contains a paper titled: "Cerebral Specialization and Adaptive Strategies in a Dichotic Movement Task in Adults with and without Down Syndrome".

Acknowledgements

I have so many people to thank, I don't really even know where to start. So I guess I'll just start rambling and hope I don't miss anyone. Probably the best thing to do would be thank everyone, à la Hollywood, in order of appearance:

My parents, my brother, my sister, and the rest of my family who have supported both emotionally and, many times, financially.

My two U of T buddies, Aurora and Sandy, I'm glad I had the two of you to make the transition and my life here much easier and enjoyable (although I am still not fluent in Chinese or Croatian). I'd especially like to thank Aurora for not killing me for not always being tidy and for never putting my shoes on the rack.

My supervisor Digby, what would I have done without your advice, guidance, open-door policy, fun-loving attitude and all manners of support over the last two years. I am really looking forward to the next few years and beyond where we can continue to work together.

My roommate Netty, although I didn't know you from a whole in wall when we signed the lease, I'm really glad, despite all the advice against it, I took the risk of moving in with a Dutch girl. The only downfall is that the words "come play" will forever strike fear into my heart. Oh yeah, please, will you and Aurora clean up your own eggs next time.

The faculty here at Mac and across Canada who I have gotten to know over the last few years. I would especially like to thank my committee members, Dr. Dan Weeks, Dr. Jan Starkes, Dr. Tim Lee, and Dr. Dominic Simon. Thanks for all your guidance and the benefits of your experience and knowledge.

John Moroz, Lorne Tulk, and Chris Watson for all their efforts in providing for me the means and support for my data collection.

All the people, who are now mostly my friends, I have met over the two years here. Specifically: The 'Fest boys: El Dictator Rod and Fast Twitch Teddy, Grote David, Cline Kevin, Baby Hook Doug, Skip Jamie, HemaphroDitor, Johnny "Don't call me Gi-ani" Parise, Quincy All-my-doe, God - Opps I mean Gord, Duke Luc, Princess Nikki, Queen Rachel, Little Cutie Jen, Tara -The Pulse of IWC, Grade 9 Dancing Laura, and all those I might have forgotten. Thanks to all of you and those I didn't mention for making these years so interesting and fun.

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Prologue

Over the last decade, a model of atypical cerebral specialization has been developing to explain verbal-motor deficiencies specific to individuals with Down syndrome. The key aspect of this model is the suggestion that the area in the brain specialized for speech perception is located in the right hemisphere: a pattern of brain organization opposite to what is typically found in the general population (see Chua, Weeks, & Elliott, 1996 for a review). The work that inspired the investigations resulting in the development of this model began with research into the language development difficulties often associated with Down syndrome (Hartley, 1981; Pipe, 1983). These early studies investigating this phenomenon utilized the dichotic listening paradigm (Kimura, 1961).

The dichotic listening procedure is a non-invasive neuropsychological test that was developed to assess cerebral lateralization for language processing. The procedure involves the simultaneous presentation of different pieces of auditory information to each of the participant's ears. Typically, the information presented to the subject is verbal and the participant is required to recall the information presented to both or just one ear. Because the major auditory pathways originating at the ear project to the contralateral hemisphere, any ear advantage (the subject being more successful at recalling information presented to one ear than the other) is assumed to reflect specialization of the contralateral hemisphere for the perception of that particular type of auditory information (see Bryden, 1982 for a review).

Utilizing the dichotic listening procedure, right-handed individuals from the general population typically demonstrate a right ear/left hemisphere advantage for the processing and recall of verbal information. These findings, along with clinical evidence from persons with unilateral brain damage and studies utilizing sodium amytal suggest that the centre for speech perception is usually specialized to the left hemisphere (see Segalowitz & Bryden, 1983 for a review). However, a meta-analysis of the research examining the cerebral specialization for speech perception in individuals with Down syndrome revealed that this population has a left ear/right hemisphere advantage when compared to their peers matched for chronological and mental age or a theoretical value of zero ear advantage (Elliott, Weeks, & Chua, 1994).

From this early dichotic listening research, it was suggested that this atypical lateralization may actually reflect a complete reversal of brain organization in this population (Hartley, 1981). However, further research has not supported this claim. Specifically, it has been demonstrated that individuals with Down syndrome have similar brain organization for almost all other processes. For example, the areas specialized for the programming of muscular forces (Elliott, 1985), tactile and visual-spatial processing (Elliott, Pollock, Chua, & Weeks, 1995), and even speech production (Heath & Elliott, in press) have all been found to be lateralized in a typical fashion. Thus, it appears that the differences in brain lateralization are restricted to the areas involved in speech perception.

Though the differences in brain function appear to be limited to speech perception, the effects of this atypical cerebral specialization go beyond simply the reception and recall of verbal information. Most importantly, it seems that the biological dissociation of the centres for speech perception (right hemisphere)(Chua et al., 1996) and movement programming (left hemisphere)(Elliott, 1985) may cause population-specific deficiencies in the ability to program and execute single and sequential movements based on verbal cues (Elliott, Weeks, & Gray, 1990; Le Clair & Elliott, 1995). The three studies presented below were designed to directly test the model of biological dissociation.

The first study compares the ability of individuals with DS to process visual versus verbal movement cues. The second study introduces a new adaptation of the dichotic listening procedure designed to examine cerebral specialization for speech perception and movement organization as well as interhemispheric communication. Finally, the third study employs this new technique to test and clarify the model of biological dissociation; that is, atypical cerebral specialization for speech perception and disruptions in motor performance when goal-directed movement must be organized on the basis of verbal information in individuals with DS.

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Section I

The Processing Speed of Visual and Verbal Movement Stimuli by Adults with and without Down Syndrome

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Abstract

Previous research has indicated found that individuals with Down syndrome (DS) have difficulties in processing auditory information for the planning of movements relative to their peers with undifferentiated developmental handicaps. This modality-specific information-processing difficulty has been found for the preprogramming of goal-directed aiming movements (Le Clair & Elliott, 1995) and in simple reaction times (Davis, Sparrow, & Ward, 1991; Hermelin, 1964). The purpose of the present study was to assess whether or not a model of atypical cerebral specialization for the perception of speech sounds, proposed by Elliott and colleagues, could explain these findings. Thus, participants performed a choice reaction aiming task under three conditions. Colour-coded targets were cued by a visual cue at the target location, a visual cue remote from the target location, or a verbal cue identifying the target. Results revealed that while the reaction times did not differ between the two groups with handicaps, the participants with DS, unlike the two control groups, had significantly longer movement times in the verbal than in two visual conditions. These results support the model of biological dissociation.

The Processing Speed of Visual and Verbal Movement Stimuli by Adults with and without Down Syndrome

It has been demonstrated many times that individuals with Down syndrome (DS) initiate and complete movements more slowly and with greater variability than their non-handicapped peers of a similar chronological age (see Johnson & Olley, 1971 for a review). In order to determine whether these delays in movement initiation are the result of the developmental delays associated with DS, or whether these individuals are functionally different from the general population, the majority of the studies reviewed use a control group of individuals with undifferentiated developmental handicaps (UnDH) of a similar chronological and mental age. Although Anwar (1981) suggested that individuals with DS are slower than their peers with UnDH, a review of the more recent literature reveals that the results are equivocal. While there are a number of studies that have shown that individuals with DS are slower than their peers with UnDH (Berkson, 1960; Davis, Sparrow, & Ward, 1991; Henderson, Illingworth, & Allen, 1991; Hermelin, 1964; Hermelin & Venables, 1964), there are just as many that have shown that there are no differences between the two groups (Inui, Yamanishi, & Tada, 1995; Knight, Atknison, & Hyman, 1967; Mack & MacKay, 1989; MacKay & Bankhead, 1983; Miezejeski, 1974). Interestingly, of the studies reviewed, none have shown that groups with DS to be faster than groups without DS.

In a more recent review of the information processing literature (cf. Anwar, 1981), an interesting pattern emerged. Welsh and Elliott (in press) reported that when differences were found between the individuals with DS and UnDH, the stimulus that the participants were required to react to was auditory while no differences existed when reacting to visual stimuli (cf. Henderson et al., 1991). This finding is typified by two specific studies. First, Hermelin (1964) conducted a study in which the participants performed a simple reaction time task under a variety of different precue and stimulus conditions. Specifically, participants were required to lift their finger to either a light or a tone after being cued visually or auditorily. Hermelin (1964) found that, while the participants with UnDH reacted with greater speed to the sound than the light, the individuals with DS, regardless of the modality of the precue, were slower in reacting to the auditory stimulus than the visual stimulus. Moreover, there were no differences between the two groups in reaction time when they were reacting to light.

Some years later, Davis et al. (1991) attempted a replication of this work and compared the abilities of individuals with and without DS to react to either a light, a sound, or a combined light-sound condition. More importantly, they attempted to answer the question of why differences may exist by partitioning reaction time into premotor and motor time, which, following the work of Botwinick and Thompson (1966) and Weiss (1965), has been assumed to provide an indication of perceptual-cognitive processing time versus peripheral time, respectively. Although Davis et al. (1991) found that the young adults with DS had longer total reaction times in all conditions, the pattern of results was very similar to those found by Hermelin (1964). Specifically, while both groups of individuals without DS had shorter reaction times to the sound than to the light, the individuals with DS were only slightly and non-significantly faster in reacting to sound than to the light. Further, and more importantly, although premotor times (central processing time) were statistically identical for the light condition for the two groups with developmental handicaps, persons with DS had significantly longer premotor times in the sound only condition. This finding, in line with Hermelin (1964), indicates that individuals with DS have relative difficulties in processing auditory information used in the production of movement.

Although there is evidence to suggest that there is a difference between those with DS and UnDH in their ability to quickly process auditory information, the question still remains as to why this difference exists. The relative inability of individuals with DS to respond quickly to auditory stimuli may be explained by a variation of a model of atypical cerebral specialization proposed by Elliott and colleagues (see Chua, Weeks, & Elliott, 1996 for a review). The main tenet of this model is that the areas responsible for speech perception are atypically specialized to the right hemisphere in persons with DS. While, to date, this model has only been used to explain verbal-motor difficulties in individuals with DS (for example, Elliott, Weeks, & Gray, 1990), there is some electrophysiological evidence to suggest that people with DS are atypically lateralized for simple auditory sounds as well (Miezejeski, Heaney, Belser, & Sersen, 1994; Weeks, Chua, Elliott, Weinberg, Cheyne, & Lyons, 1997). Thus, the atypical lateralization in people with DS may extend to sounds in general. Specifically, because both hemispheres must be involved in the planning and execution of movement based on auditory information, the observed delays may be due to the slowing and/or loss of information due to interhemispheric communication.

The purpose of this study was to attempt a replication of the earlier findings that individuals with DS have modality specific information-processing deficiencies (Davis et al., 1991; Hermelin, 1964). These earlier studies, however, only used single auditory tones as the reaction time stimulus. In the present study, partcipants were required to complete a choice reaction time task where they were cued to the target either visually or verbally (i.e., the spoken colour word of the target). According to the model of biological dissociation, this relative deficiency, as in the earlier simple reaction time studies, should also be most prominent when participants are required to react to an imperative stimulus that is verbal. Thus, the present study examined whether the modality specific simple reaction time deficiency occurs when the auditory cue is verbal.

Methods

Participants

There were three groups in this study. One of the groups consisted of 13 adults with Down syndrome (chronological age (CA) of 29.5 years and mental age (MA) of 7.1 years). The participants in a second group were 14 adults with UnDH who had similar a CA (29.6 years) and MA (9.0 years). The individuals in these two groups were recruited from the Dundas Learning Centre and the Etobicoke E.T.S. The final group consisted of 14 individuals from the McMaster University community with a similar CA (27.6 years) to participants in the other groups (Table 1). For inclusion in the study, each participant was required to meet the following criteria: 1) right-handed (Bryden, 1977); 2) normal or corrected-to-normal vision; 3) the ability to distinguish between the colours "blue" and

Table 1

Group Characteristics Including Number, Gender, and Mean and Standard Deviations () of Chronological and Mental Age (years).

Group	Number	Gender	Chronological Age	Mental Age
Non-Handicapped	14	8 males, 6 females	27.6 (3.8)	-
Undifferentiated DH	14	7 males, 7 females	29.6 (3.6)	9.0 (1.8)
Down syndrome	13	8 males, 5 females	29.5 (5.4)	7.1 (1.8)

Note. Mental age was not assessed in the participants without handicaps.

"green" based on verbal presentation of the colour word; and, 4) an auditory threshold sensitivity of at least 40 dB in both ears at the frequencies of 500 Hz, 750 Hz, 1000 Hz, 2000 Hz, 3000 Hz, and 4000 Hz as determined by pure tune audiometry. All individuals were compensated for their time. Of the 48 individuals that were screened, 7 individuals were excluded from the study because they were found to be left-handed.

Apparatus

The movement environment included a start position (1.5 cm diameter yellow button) and two target buttons embedded in a rectangular metal box (43 cm long X 30 cm wide X 4 cm high) painted black. The targets, one blue and one green plastic button (1.5 cm diameter), were located on both sides of, and in line with, the start position. The distance from the start position to each of the buttons was 16 cm. Finally, located on either side of the start position, 5.5 cm and 7.0 cm from the start position and arranged in a line perpendicular to the line of the targets, were four light emitting diodes (LEDs). Two of these LEDs (one on each side of the start position) were green and the other two were blue. The target lights and LEDs were triggered to illuminate by the experimenter using a Lafayette Multisecond Timer (model 50013). The illumination of the target buttons or of the flanking LEDs created the conditions in which the participant was cued directly or indirectly about the target for a trial.

All verbal stimuli consisted of specially created audio wave files of a male voice speaking the colour words of the target buttons (i.e., "blue" or "green"). These files were prepared, using Soundscape: SSHDR1 – Version 1:18, such that identical tracks were presented simultaneously (within .25 ms) to both ears. All verbal stimuli were presented, via headphones (Koss Pro/466), from an external computer (Pentium-Compupartner with Sound Blaster AWE64). The signal of the wave file sent from the computer to the headphones was simultaneously sent to a Lafayette Voice Response Time Control (model 6602 A) which then triggered the same Lafayette Timer employed for the visual stimuli. The Lafayette Timer and starting and target buttons were then interfaced with a Lafayette Interval Timer (Model 63520). These devices were interfaced such that one digital timer started simultaneously with stimulus presentation. This timer was stopped when the participant's hand was lifted from the starting position, thus measuring reaction time. The removal of the hand from the starting location also started a second timer which was stopped when either of the two target buttons were depressed, thus measuring movement time.

Procedures

For the individuals with DS and with UnDH, testing involved two sessions of 30-45 minutes, each session being separated by at least two days. On the first day of the study, pure tone audiometry and an assessment of mental age, using the Peabody Picture Vocabulary (Form L), was carried out. At the beginning of the second session, handedness was assessed by examining preferred hand use on three tasks from a standard handedness questionnaire (Bryden, 1977). Specifically, we identified the preferred hand for the performance of: 1) writing their name; 2) eating soup with a spoon; and, 3) throwing a ball. While the individuals from the general population reported their hand preference for these tasks, the individuals in the other two groups were required to demonstrate the tasks after the particular implements were placed directly in front of them along the midline of their body. For inclusion in the study, the right hand was required to be the preferred hand for each of these tasks. The final screening procedure was a colour recognition task that involved the individual pointing to "blue" and "green" circles randomly placed on a white piece of paper amongst an equal number of other red and yellow circles. These tests were performed to ensure that all participants had similar characteristics (i.e., mental age and handedness) and to ensure that all participants possessed the ability to perform the experimental task. Following these final screening tests, the participant immediately began the experimental phase of the study.

For the individuals from the McMaster community, all testing was completed in one session lasting approximately 45 minutes. The session began with the hearing test (pure tone audiometry), colour discrimination test, and adapted handedness questionnaire. Upon the completion of these tasks, this group immediately began the experimental phase of the study.

The experimental phase consisted of 6 blocks of 24 trials (144 total trials) of a two choice reaction time task. Trial initiation was self-paced. The sequence of events was as follows: The experimenter would say "Ready?" indicating that the participant could initiate the trial at any time. Participants would then depress the start button. The depression of the start button by the participant was the signal to began a 1 to 3 s random foreperiod after which one of the two targets was signaled by one of three possible cue types. The subject was required to move to the appropriate target as quickly as possible. The next trial began, again, with the same "Ready?" signal from the experimenter.

Participants were signaled to move to one of the targets under two different visual and one auditory condition. The first of the two visual conditions was termed the direct mapping condition. In this condition the target itself was illuminated. The other visual condition was termed the visual indirect mapping condition because, in this situation, the target itself did not light up, but two of the similarly coloured LEDs, which flanked the home position, were illuminated. For example, if the two blue buttons were illuminated, the participant was required to move to the blue target. This condition served as a control for the abstract nature of the verbal signal. The verbal condition consisted of the presentation of the colour words of the target, in a male voice, from the computer to the participant via the earphones.

For each condition, participants completed two blocks of 24 trials; one block consisting of movements with the right-hand and the other block of movements with the left-hand. At the beginning of each block, the participant was given 4-6 practice trials. Thus, the total number of trials was 168-180. Within each block, the location of the target was randomized with the constraint that they occurred equally often and no more than three times in a row. Hand order as well as modality of stimulus was counterbalanced within each group. Participants completed both right and left hand blocks of each condition before starting a new condition.

Finally, as the key theoretical interest of this study was information processing speed, an emphasis was placed on the speed of reaction and movement to the target. Any trial in which the home position or target was not properly depressed or when the participant moved to the wrong location, was considered an error. These trials were repeated at the end of that block (less than 1 % of all trials were errors).

Data Analysis

Because of the positive skew associated with reaction time (RT) and movement time (MT) distributions, trials in which the RT or MT was 2 standard deviations beyond the mean value for the subject for that condition were eliminated. The means for RT and MT data were recalculated and then submitted to a 3 Group (Non-H, UnDH, and DS) X 2 Hand (Left, Right) X 3 Condition (Direct, Indirect, and Verbal) mixed ANOVA with repeated measures on the last two factors.[1] All post hoc analyses were performed using Tukey's HSD with alpha set at .05.

Results

Although overall group differences were not the focus of the study, it is interesting that the post-hoc analysis of the main effects for Group in both RT, $F(2, 38) = 20.28$, $p < .0001$, and MT, $F(2, 38) = 26.30$, $p < .0001$, revealed that, while the group without handicaps had the shortest RTs and MTs (334 ms and 170 ms, respectively), the individuals with DS (631 ms and 663 ms, respectively) were not reliably different than those with UnDH (559 ms and 637 ms, respectively) (see Table 2). There was also a main effect for Condition in both RT, $F(2, 76) = 50.39$, $p < .0001$, and MT, $F(2, 76) = 8.18$, $p < .001$. For RT, post hoc analysis revealed that the verbal condition elicited the shortest reaction times with the direct mapping condition also eliciting shorter RTs than the indirect mapping condition. For MT, the pattern was slightly different. While the participants obtained the target with equal speed in the indirect mapping and verbal conditions, they reached the target sooner when moving in the direct visual mapping

Table 2.
Mean Reaction Time (ms) and Movement Time (ms) as a Function of Group, Hand, and Condition.

	Left Hand			Right Hand		
Group	Direct	Indirect	Verbal	Direct	Indirect	Verbal
Reaction Time						
Non-handicapped	322	396	274	334	402	278
Undifferentiated DH	474	724	446	504	736	467
Down syndrome	584	798	486	579	860	476
Movement Time						
Non-handicapped	159	179	183	156	169	176
Undifferentiated DH	573	687	620	575	740	626
Down syndrome	623	677	739	635	605	699

condition.

Of greater theoretical interest, however, were the significant Group X Condition interactions for RT, F (4, 76) = 4.11, $p < .005$, and MT, F (4, 76) = 6.10, $p < .0005$. Post hoc analysis of the RT interaction revealed that, while the non-handicapped group was not different across conditions, the two groups with handicaps had longer RTs in the indirect mapping condition than in the other two conditions (see Figure 1). Interestingly, the predicted information processing difficulties in the verbal condition for the group with DS did not appear.

Although the modality specific difficulty for the individuals with DS was not found in RT, it was evident in MT. Specifically, the post-hoc analysis of the Group X Condition interaction for MT revealed that, while the two groups without DS showed an identical pattern of results for RT, the individuals with DS were slower in the verbal condition than both the direct and indirect conditions, which were not different from each other (see Figure 2). Furthermore, while the two groups with handicaps were not different from each other in the two visual conditions, the MTs of the participants with DS were significantly longer than the participants with UnDH in the verbal condition.

On a final note, there was no main effect for Hand in RT, F (1, 38) = 1.26, $p > .05$, or MT, F (1, 38) < 1, nor were there any interactions involving Hand. While hand differences are typically observed for tasks involving rapid aiming movements (see Elliott & Chua, 1996 for a review), the low accuracy demands and spatial uncertainty (Carson, Chua, Goodman, Byblow, & Elliott, 1995) of the movement task employed in the present study may have washed out differences which are typically observed.

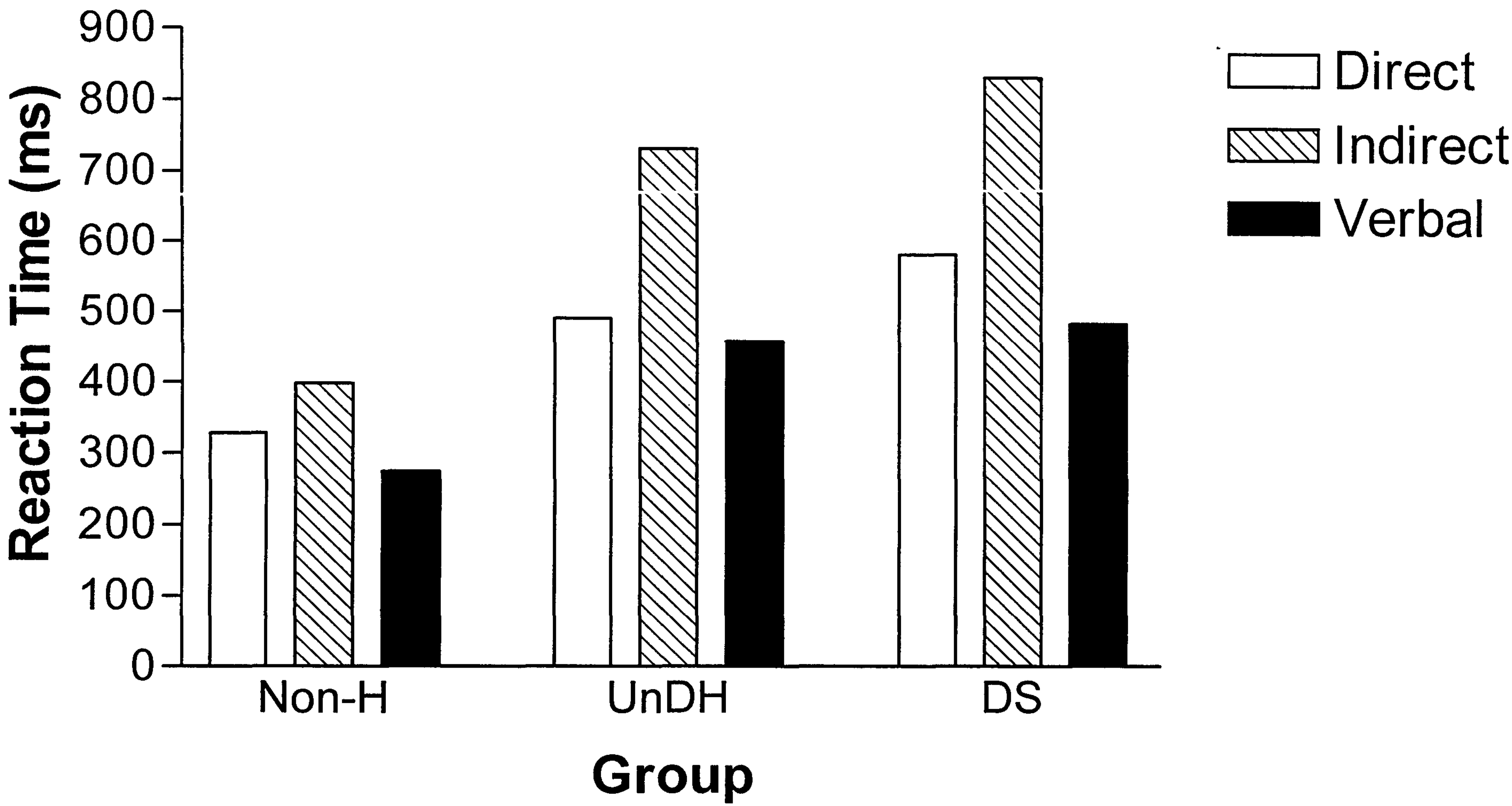

Figure 1. Reaction time as a function of Group (Non-H: Non-Handicapped; UnDH: undifferentiated developmentally handicapped; and, DS: Down syndrome)and Condition.

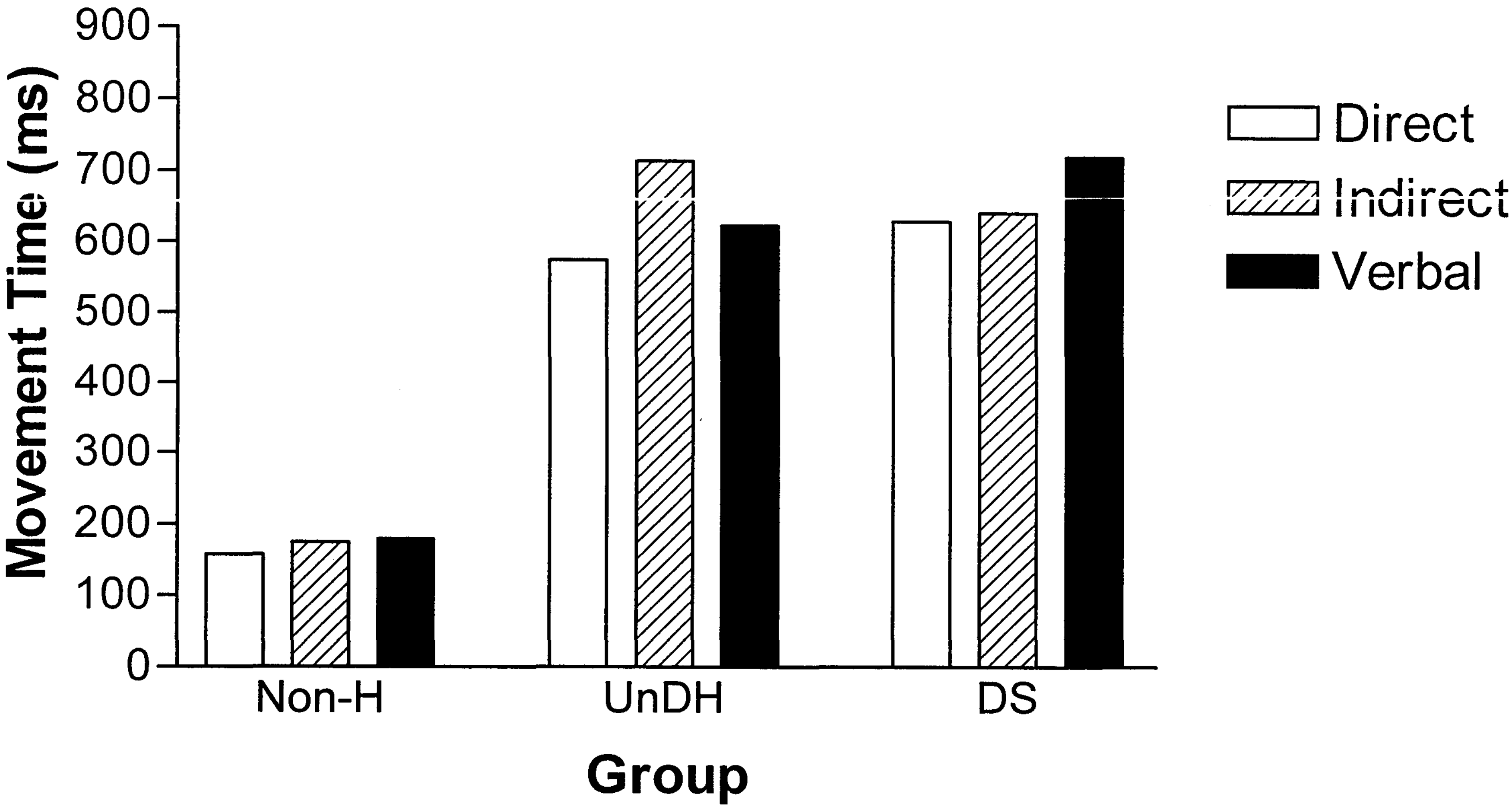

Figure 2. Movement time as a function of Group (Non-H: Non-Handicapped; UnDH: undifferentiated developmentally handicapped; and, DS: Down syndrome)and Condition.

Discussion

The purpose of the present study was to investigate whether the auditory specific information processing difficulty for people with DS (Davis et al., 1991; Hermelin, 1964) extends to verbal movement stimuli. The results of the present study are consistent with the findings of the previous studies in that the participants with DS were differentially affected by the verbal condition. Specifically, although it seemed that the auditory cues had the same alerting effects for the individuals with DS (no differences in RT for verbal stimuli), their ability to process that information and make a final movement based on that information was slowed as seen in their longer MTs. Thus, these results provide support for hypothesized modality specific information processing and decision making difficulties in individuals with DS.

A possible explanation for the modality specific information processing difficulty may be found in the model of biological dissociation (Chua et al., 1996). This model of cerebral specialization for individuals with DS suggests that the brain of the individual with DS is specialized in a manner similar to the brain of those from the general population except that the area for speech perception is atypically specialized to the right hemisphere. This model has developed from the repeated finding of left-ear advantage for speech sounds during dichotic listening (Elliott, Weeks, & Chua, 1994) and has been previously employed to explain the findings that individuals with DS have relative difficulties in using verbal precue information (Le Clair & Elliott, 1995) and learning a novel sequence of movements from verbal instruction (Elliott, Gray, & Weeks, 1991).

If, as according to the model, the area for speech perception in individuals with

DS is located in the right hemisphere, the pattern of results obtained in the present experiment would logically follow. Firstly, as the sound of the word would carry substantial alertive information, the participants with DS were able to react and initiate their movement just as fast as their peers without DS. However, since, as the model would predict, the decoded verbal movement information (processed in the right hemisphere) must be transmitted across the corpus callosum to the movement executive (left hemisphere) before final movement plans can be completed, a delay at the beginning of the movement would cause the differential increase in MT. This kind of risky "initiate the movement first, and then figure out the final destination while the movement is being completed" strategy has been observed in individuals with DS in an aiming study involving distracting movement stimuli (Kulatunga-Moruzi & Elliott, 1999).

Evidence that another difference may exist between the two groups of participants with handicaps was the finding that, while the RTs of both groups with handicaps were similar across both visual cueing conditions, only the participants with UnDH had longer MTs for the indirect visual stimuli than for the direct visual stimuli. Once again, if MT is indicative of final decision making and movement planning, this finding would suggest that the persons with DS were able to quickly use indirect visual information to prepare and execute movements. Perhaps this translational difference is indicative of persons with DS having a relatively better ability than their peers with UnDH to perform abstract stimulus-response compatibility tasks. In sum, the results of the present study support the idea that individuals with DS have a modality specific information processing difficulty relative to their non-handicapped and handicapped peers without DS.

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Author Notes

This research was co-funded by the National Down Syndrome Society (NDSS) and the National Institute of Child Health and Human Development (NICHD), NIH # 1 R01 HD37448-01. The Authors would like to extend a warm thank you to all those at the Dundas Learning Centre and the Toronto Association of Community Living who made this study possible. We would specifically like to thank Ann Pearson, Agnes Samler, Lorry Cumming, Shelia Magee, and all the staff at the Etobicoke E.T.S. who helped us with this study. The Authors would also like to thank John Moroz for his technical support in the construction of the apparatus, Lorne Tulk for his help in the creation of the audio files used in this study, and Chris Watson for his help in data collection.

Footnotes

1. The initial analysis included Location as a factor, but it was subsequently dropped from the analysis because there were no effects that involved location. Further, although the adults with DS had a significantly lower MA than the adults with UnDH (t (25) = 2.81, $p < .01$), the pattern of results was not altered when a separate analysis was performed using MA as a covariate.

Section II

Gender Differences in a Dichotic Listening and Movement Task: Lateralization or Strategy?

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Abstract

Although the dichotic listening procedure has been used as a non-invasive neuropsychological technique for assessing laterality of speech perception, it has tended to underestimate laterality proportions found in clinical studies (Segalowitz & Bryden, 1983). These underestimations may be due to dichotic procedures being susceptible to strategy effects, attentional biases, and/or memory effects that may obscure functional differences. In the present study, we used an adaptation of the dichotic listening procedure that was less sensitive to these confounding effects. Participants were required to move as quickly as possible to one of two colour-coded targets following verbal cues presented via headphones. Conditions of cue word presentation were monaural, (e.g., "blue" in one ear and a blank track in the other), dichotic-same (e.g., "blue" in both ears), and dichotic-different (e.g., "green" in one ear and "blue" in the other). By combining the selective dichotic listening procedure with a rapid choice reaction aiming movement, specific predictions were made about reaction time and intrusion error patterns. Results revealed that the participants demonstrated a strong right ear advantage in reaction time and correct responses. As all participants showed a 20.8 – 62.5 % difference between the performance of the two ears, it appears that this adaptation is very sensitive to lateralization for speech perception. Also of interest were gender differences in laterality for speech perception. It has been suggested that females are less lateralized for speech perception than males. Results of the gender analysis indicate that these differences may be due to differences in strategic approach to the task rather than any functional difference between the cerebral hemispheres.

Gender Differences in a Dichotic Listening and Movement Task: Lateralization or Strategy?

The dichotic listening procedure was first used to study attentional strategies and the ability of a "central processor" to filter out unwanted information (Broadbent, 1954). Following this work, Kimura (1961) adapted this procedure in an attempt to develop a non-invasive neuropsychological technique for identifying the cerebral hemisphere specialized for language processes. The early procedures involved the simultaneous presentation of word pairs to the two ears. Subjects were simply required to recall as many words as possible. It was found that right-handed people generally (85-89 % of the population, see Bryden, 1988 for a review) exhibited a right ear advantage (REA). That is, right-handers recalled more of the words presented to the right ear than to the left ear. The explanation of this finding was that, although there are both ipsilateral and contralateral neural pathways that connect the ears to the centres for speech perception, during the performance of the dichotic listening task, the minor ipsilateral pathways are inhibited allowing the dominant contralateral pathways preferred access to the areas specialized for speech perception (Kimura, 1967). Thus, because the right ear has "direct" access to the hemisphere best able to perceive and decode speech sounds, people typically perform better with their right ear than with their left ear.

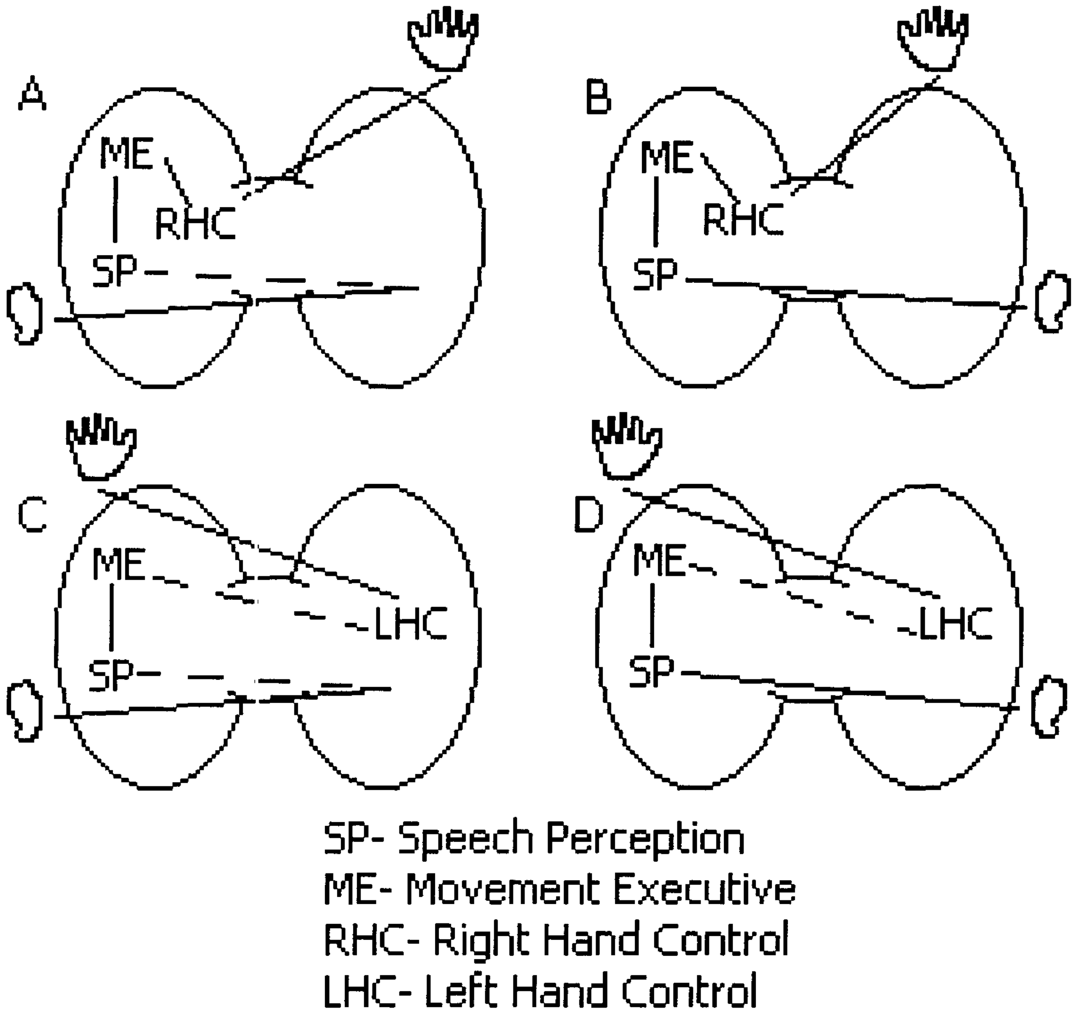
This early procedure was effective, but not without its critics. The free recall aspect of the protocol has been criticized for confounding functional differences between the hemispheres with attentional biases and short-term memory (for example, Kinsbourne, 1970). Thus, since the first experiments, the dichotic listening procedure has gone through a number of revisions. For example, in an attempt to decrease the possible effects of these right side biases inherent in the free recall of information, Bryden (1963) instructed participants to report what they heard in either the right or the left ear first on different blocks of trials. Findings of this early attentional study indicate that, although the a distinct REA was found, the order of report did affect left ear performance. The procedure has also been criticized for lack of sensitivity. Specifically, although the estimates of the right-handed population that are left hemisphere specialized for speech perception are fairly accurate (85 – 89 %) based on the results of the dichotic listening procedures, it has been pointed out that the tests underestimate the proportion of the population (95.5 %) predicted from clinical studies (Segalowitz & Bryden, 1983). Perhaps part of this discrepancy is because dichotic tasks are generally performed well, making differences between the two ears small (Bryden, 1988).

Just as ear advantages have been employed as an indication of cerebral specialization for speech perception, manual asymmetries on movement tasks have been used as an indication of contralateral hemispheric dominance for movement organization. Manual asymmetries on tasks such as rhythmic finger and limb tapping (Todor, Kyprie, & Price, 1982), transfer of training (Taylor & Heilman, 1980), and accuracy and timing of rapid aiming movements (Elliott & Chua, 1996) have all been used as indices of cerebral specialization for movement organization and production. The results of these studies indicate that, for the right-handed individual, the left hemisphere plays a dominant role in movement organization. Although the left hemisphere has been suggested to have this executive role in movement organization, it must be remembered that it is the motor areas of the contralateral hemisphere that deliver the final movement directives to the limbs. Moreover, there is also the possibility that the right hemisphere may have a role in preparing aiming movements with a high degree of spatial uncertainty (Carson, Chua, Goodman, Byblow, & Elliott, 1995; see Elliott & Roy, 1996 for a review). The purpose of the present study was to combine the dichotic listening and manual asymmetry paradigms, in an attempt to test the current models of cerebral specialization for speech perception and movement organization.

A similar dichotic methodology involving a manual response was used by Jancke and Steinmetz (1994). They required their participants to monitor dichotic consonant-vowel pairs and instructed them to press a button with a cued hand when they perceived a target syllable in either ear. Eighty-nine percent of the right-handed and 63 % of the left-handed participants demonstrated a right ear/left hemisphere advantage in reaction time. These laterality percentages are similar to estimates of cerebral specialization for speech perception utilizing traditional dichotic methodologies (Bryden, 1988). However, like many of the earlier studies employing the dichotic listening procedure, the laterality effects using Jancke and Steinmetz's procedure are still confounded with possible attentional strategy. Specifically, the participants may have demonstrated a right side advantage because they typically focus their attention to their dominant right side which may make them more sensitive to information presented to that right ear. Further, the role the left hemisphere plays as the movement executive, may also have contributed to the right side advantage found in this study.

The methodology developed for the present study avoids the pitfalls of associated attentional biases and lateralized limb control by combining the selective dichotic listening paradigm (Hiscock & Kinsbourne, 1977) with a rapid choice reaction aiming task. Specifically, the participants were presented verbal target information, either monaurally or dichotically, and were required to focus their attention on the information presented to one of their ears and then make a rapid aiming movement to the target cued in that ear. By using factorial combinations of ear and hand, specific predictions can be made about hand and ear advantages based on the time taken for within- and between-hemisphere communication.

For most right-handed individuals, the left cerebral hemisphere plays a special role in both speech perception and the organization and control of voluntary movement. Thus, if target information is presented dichotically, and the participants are instructed to pay attention to the right ear while responding with the right hand, they should enjoy a reaction time, and perhaps a movement time, advantage as compared to conditions involving other ear-hand pairings. If Kimura's (1967) hypothesis about the occlusion of the ipsilateral auditory pathways is correct, this temporal advantage would result because the processing required to complete the task is restricted to the left cerebral hemisphere (see Figure 1B). Assuming that the left hemisphere must be involved in the perception of speech and the organization of accuracy-demanding limb movements, the left ear-left hand dichotic condition should lead to the longest reaction times and movement times. This temporal disadvantage would result because this condition involves the greatest between-hemisphere transfer of information (Jancke & Steinmetz, 1994). That is, the verbal information specifying the target, as well as information required for the regulation



<u>Figure 1.</u> Schematic of predicted paths of intra- and interhemispheric information transfer. The conditions are: A) left ear presentation, right hand movement; B) right ear presentation, right hand movement; C) left ear presentation, left hand movement; and, D) right ear presentation, left hand movement. (Solid line indicates direct links between areas. Dashed line indicates transmission through corpus callosum).

of the movement may have to cross and recross the corpus callosum (see Figure 1C). The left ear-right hand and right ear-left hand pairings should be intermediate because movement organization based on this type of verbal input may involve just a single between-hemisphere transfer of information (see Figure 1A and D). These predictions are based on the assumption that if the speed of the response is emphasized, movements will be programmed based on the first available information.

The temporal advantages predicted in processing time may also generalize to movement error if one assumes that interhemispheric transfer can result in degradation or loss of information. Thus, for the left ear, a combination of the temporal disadvantage and degradation of the information may result in more movements to the target presented to the right ear even though the left ear was the focus of attention.

Also of interest was the examination of possible gender differences in this verbal-motor task. Although it is generally assumed that females are less lateralized than males for speech perception (Segalowitz & Bryden, 1983), the evidence is inconsistent. For example, Lake and Bryden (1976) and Piazza (1980) found that females had less of a right ear advantage to verbal stimuli than males, while Bryden, Munhall, and Allard (1983), Carr (1969), and Jancke and Steinmetz (1994) found no differences between the genders. Differences in the results of these studies may be due to the variations of the types of tasks used. To support this idea, Jancke, Steinmetz, and Volkmann (1992) found little correlation between the lateralities found when the same participants performed seven different dichotic tasks. Thus, ear advantages found in a variety of these tasks may be assessing things other than just the "hardware" of the hemispheric specialization; for example, individual "software" differences related to strategy may affect performance. Thus, as Segalowitz and Bryden (1983) suggest, the differing results of studies examining gender differences in laterality for speech perception may reflect differences in the way males and females approach the task.

In support of this idea are the studies by Munro and Govier (1993) and Wexler and Lipman (1988). They had males and females performing dichotic listening tasks for extended periods of time and examined how their laterality scores changed over time. They found that the males showed a stronger REA at the beginning of the session than at the end, while the females showed the opposite pattern. Although laterality for speech perception has a structural base (see Segalowitz & Bryden, 1983), these changes over time suggest that some strategic differences or adaptations can have at least some influence.

Thus, the purpose of this study was twofold. First, we wanted to test the current models of cerebral specialization for both speech perception and movement organization with a task that combines the dichotic listening and rapid aiming movement paradigms. Second, we wanted to examine whether the suggested differences between males and females in lateralization for speech perception may be due to cerebral function.

Methods

Participants

Participants consisted of 14 members of the McMaster University community (7 males and 7 females). The mean age of the group of males was 25.5 years (ranging from

21-35) and 23.4 years (ranging from 22-26) for the group of females. For inclusion in the study, each participant was required to meet the following criteria: 1) right-handed; 2) report normal, or corrected-to-normal, vision; and, 3) no more than a 5 dB difference between the two ears in the threshold sensitivity at the frequencies of 500 Hz, 750 Hz, 1000 Hz, 2000 Hz, 3000 Hz, and 4000 Hz as determined by pure audiometry.

Apparatus and Task

Participants performed aiming movements over a black metal surface (30 cm wide X 43 cm long X 4 cm high). Embedded in the surface of the box were three coloured buttons. The starting location was a 1.5 cm diameter yellow button located in the centre of the board. The two targets were one blue and one green translucent plastic button (1.5 cm diameter) and were located 16 cm on either side of the start button at the midline.

Subjects were cued to the target locations through specially created audio files of a male voice speaking the colour words of the target buttons (i.e., "blue" and "green"). The software used to create the audio files (Soundscape: SSHDR1 – Version 1:18) allowed us to align the attack of the words to within less than 0.25 ms. There were three conditions of stimuli presentation (two control and one experimental). The three conditions were based on how the information was presented through the headphones. The first control condition involved information presented to one ear only (e.g., "blue" in left ear, blank track in right ear). The second control condition, termed the dichotic-same (DS) condition, involved the simultaneous presentation of the same word to both left and right ears. The third, and experimental, condition was the dichotic-different (DD) condition and involved the simultaneous presentation of different words to each ear (e.g., "blue" in right ear and "green" in left ear). In all conditions, similar to the selective dichotic listening procedure (Hiscock & Kinsbourne, 1977), participants were instructed to attend to one ear and then complete a movement as quickly and accurately as possible based on the information coming into the attended ear, while ignoring the information presented to the other ear, whether it was conflicting, identical, or absent.

All stimuli originated from an external computer (Pentium-Compupartner with Sound Blaster AWE64) to the subject via headphones (Koss Pro/466). The presentation of the stimuli was controlled by the experimenter and was randomly delayed 1-3 seconds from a "Ready" cue. The external computer and starting and target buttons were interfaced with a Lafayette Interval Timer (Model 63520) such that a timer started upon stimulus presentation. This first timer was stopped when the participant's hand was lifted from the starting position, thus measuring reaction time. When the subject lifted their hand from the start button, a second timer was started and subsequently stopped when either of the target buttons was depressed, thus measuring movement time.

Procedure

Prior to the commencement of testing, participants were screened for handedness and hearing impairments by employing the Bryden Handedness Questionnaire (Bryden, 1977) and pure tone audiometry, respectively. Following the screening process, subjects were shown the movement environment and then the procedure was explained. All subjects were kept naive as to the purpose of the testing.

A particular trial began when the participant depressed the start button. Upon start button depression, the experimenter gave a warning cue of "Ready". One to 3 s after the warning cue, the audio file for that trial was played and the subject was required to move as quickly and accurately as possible to the signaled target. The next trial began when the subject was ready and depressed the start button again.

The entire procedure was completed in one session that lasted approximately 40-50 min. The study consisted of 12 blocks of 12 trials. All 144 trials were blocked factorially based on reacting hand and attended ear. Condition of presentation was not blocked factorially. Single ear presentations were blocked separately from the two dichotic presentation conditions while both DS and DD presentations were randomly mixed into the same blocks. Thus, there were four blocks of single ear trials and eight blocks in which participants were presented information in both ears. The DS and DD conditions were randomly mixed into the same blocks in order to ensure that subjects were maintaining their attention on the information presented to the cued ear.[1]

In order to ensure that any ear effects found were due to lateralization and not due to a difference in the strength of the signal between the channels, the ear phones were switched (i.e., right ear phone placed on left ear) on the second block of each dichotic block. In terms of errors, the participants were instructed to react and move as quickly as they could. They were told that all other participants made errors so not to worry if they did. Participants were not told if they moved to the correct location. Finally, the location of the target was randomized within each block and the order of the blocks was randomly assigned to the participants.

Dependent Measures and Data Analysis

Reaction time (RT) and movement time (MT) were recorded from the interval timers. The final dependent measure was movement errors (ER). Simply defined, an ER occurred every time the subject completed the movement to the incorrect target. Because in the two control conditions (SE and DS), participants in all groups made an error on less than 1% of the trials, the error data were analyzed using a 2 Gender (female/male) X 2 Ear (left/right) X 2 Hand (left/right) mixed ANOVA with repeated measures on the last two factors.

Mean RT and MT were submitted to a 2 Gender X 2 Ear X 2 Hand X 3 Condition (SE/DS/DD) mixed ANOVA with repeated measures on the last three factors. Subsequent to this analysis, the errorful trials were removed from the data set and the same analysis was performed on the means of the correct trials[2]. Initially, in all these analyses, Location (near/far) was included as a factor. However, because the analyses revealed no main effect or interaction involving Location, it was dropped as a factor. All post hoc analysis was performed using Tukey's HSD with alpha set at .05.

Results

Intrusion Errors

As predicted, there was a main effect for Ear, $F\ (1, 12) = 59.3$, $p < .0001$, with participants committing significantly fewer errors when they were concentrating on their right ear ($M = 1.9$) than when they concentrated on their left ear ($M = 6.5$). Interestingly, there was also a two-way interaction between Gender and Ear, $F\ (1, 12) = 8.08$, $p < .05$.

Post hoc analysis of the interaction revealed that, while both groups of participants displayed a REA, females made more right ear errors ($\underline{M}$ = 2.4) and significantly fewer left ear errors ($\underline{M}$ = 5.4) than the males ($\underline{M}$ = 1.3 and 7.7, respectively) (see Table 1 and Figure 2).

Reaction Time

In RT across all trials, the only significant main effect was for Condition, $\underline{F}$ (2, 24) = 34.83, $\underline{p}$ < .0001; RTs to SE presentation ($\underline{M}$ = 645 ms) were shorter than those to the DS presentation ($\underline{M}$ = 840 ms), which were in turn shorter than those to the DD presentation ($\underline{M}$ = 1010 ms). While the effects for Gender, $\underline{F}$ (1, 12) = 3.22, $\underline{p}$ < .1, and Ear, $\underline{F}$ (1, 12) = 3.05, $\underline{p}$ < .11, approached traditional levels of significance, Hand effects were absent, $\underline{F}$ (1, 12) < 1. Mirroring the interaction in ERs, there was a significant interaction between Gender, Ear, and Condition, $\underline{F}$ (2, 24) = 3.56, $\underline{p}$ < .05. As evident from Figure 3, while the males demonstrated a REA in the DD condition only, the females displayed no ear advantage in any condition.

The analysis of RT on the correct-only trials revealed that the REA was enhanced when the errorful trials were removed. In this analysis, along with the main effect for Condition, $\underline{F}$ (2, 24) = 41.91, $\underline{p}$ < .0001, there was also a main effect for Ear, $\underline{F}$ (1, 12) = 7.02, $\underline{p}$ < .05. While there was a REA in RT collapsed across all conditions, post hoc analysis of the Ear X Condition interaction, $\underline{F}$ (2, 24) = 8.08, $\underline{p}$ < .005, revealed that this REA was present only in the DD condition. While Hand also interacted separately with Condition, $\underline{F}$ (2, 24) = 7.43, $\underline{p}$ < .005, with the right hand showing an advantage in the DD condition only, the three-way interaction involving Ear, Hand, and Condition was not

Table 1.

Mean Reaction Time (ms), Movement Time (ms), and Number of Movement Errors across all trials as a function of Gender, Ear, Hand, and Condition.

Gender	Left Ear		Right Ear	
Condition	Left Hand	Right Hand	Left Hand	Right Hand
Reaction Time				
Males				
Single Ear	276	295	295	317
Dichotic Same	400	420	393	399
Dichotic Different	476	500	405	410
Females				
Single Ear	361	358	344	348
Dichotic Same	430	458	427	436
Dichotic Different	594	590	604	560
Movement Time				
Males				
Single Ear	146	132	152	139
Dichotic Same	172	177	173	164
Dichotic Different	223	251	210	235
Females				
Single Ear	236	235	244	215
Dichotic Same	253	253	272	263
Dichotic Different	351	363	321	300
Movement Errors				
Males				
Single Ear	0.3	0.4	0	0
Dichotic Same	0	0	0	0.1
Dichotic Different	7.3	8.1	1.6	1.1
Females				
Single Ear	0	0	0	0
Dichotic Same	0	0	0.1	0
Dichotic Different	5.9	4.9	2	2.9

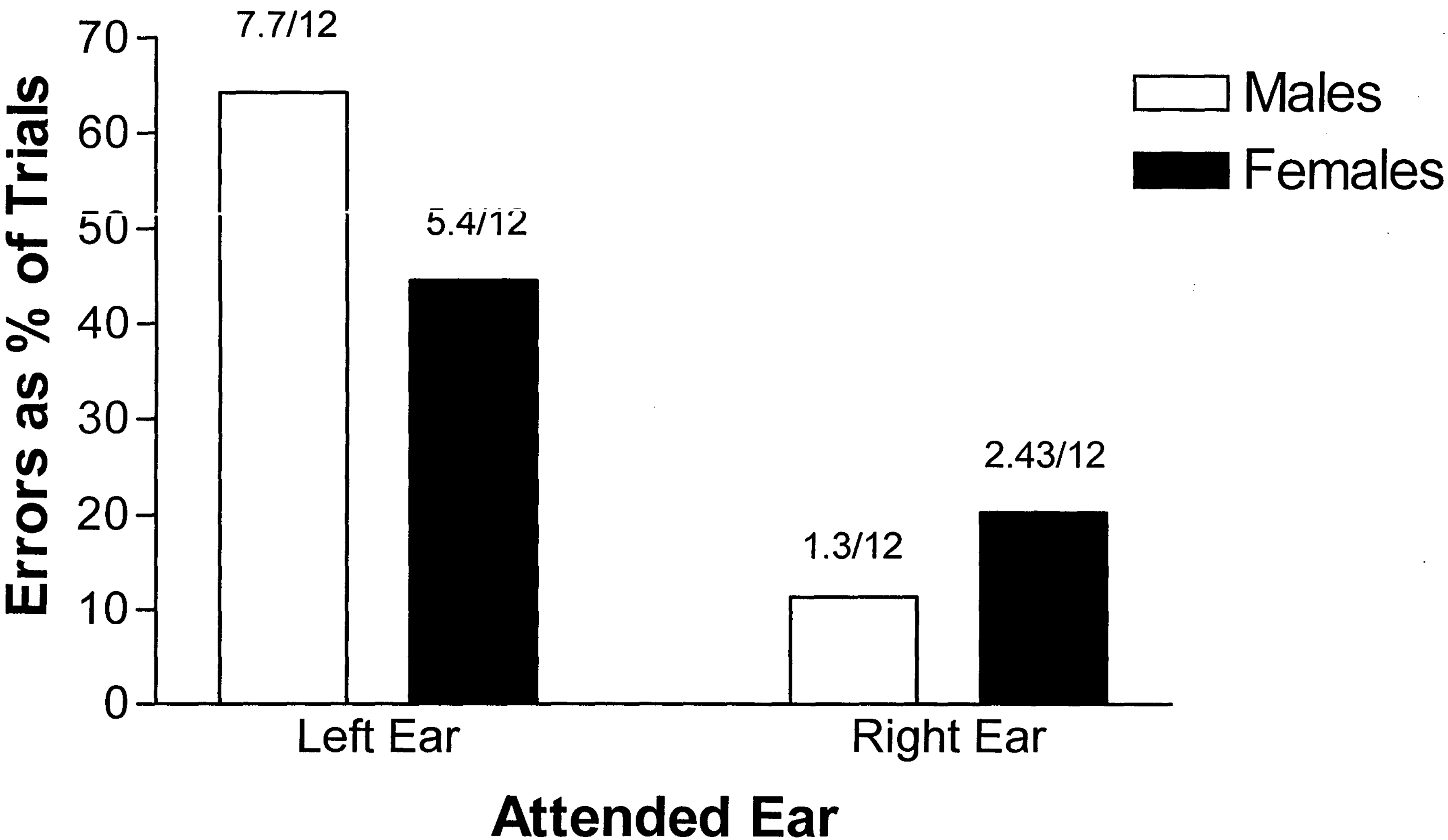


Figure 2. Percentage of Movement Errors as a function of Gender and Attended Ear.

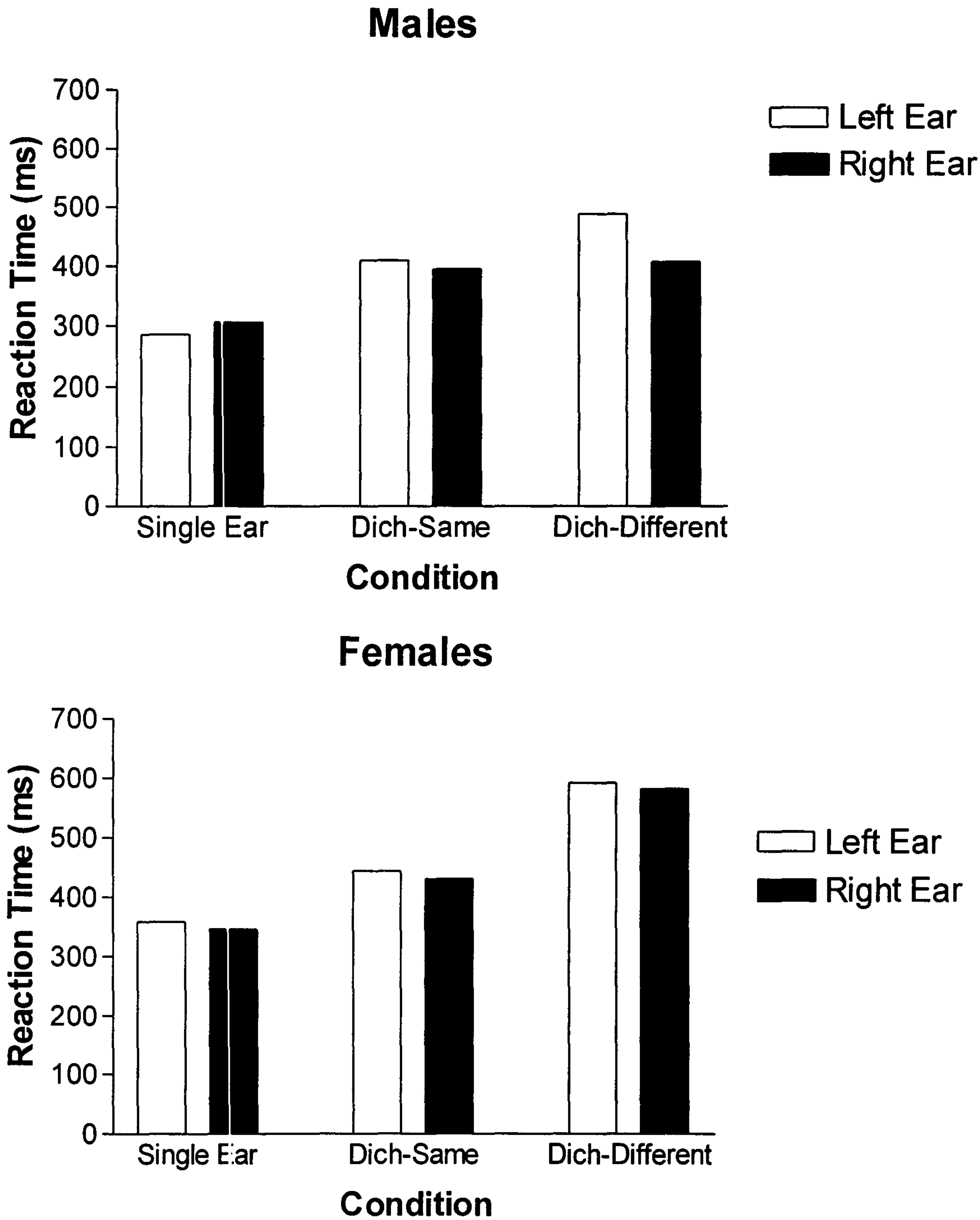


Figure 3. Reaction time (ms) of all trials as a function of Gender, Attended Ear, and Condition.

significant, $F(2, 24) < 1.0$. Finally, it is important to note that, with the errorful trials removed, the interaction between Gender, Ear, and Condition disappeared, $F(2, 24) = 1.67$, $p = .21$ (see Table 2). The interaction was lost because the female's RT increased in the error-free left ear attention condition and decreased in the error-free right ear attention condition (see Figure 4).

Movement Time

For MT across all trials, the analysis revealed a main effect for Gender, $F(1, 12) = 18.31$, $p < .005$, and Condition, $F(2, 24) = 28.98$, $p < .0001$. It was found that the males had shorter MTs ($M = 180$ ms) than the females ($M = 275$ ms) and that MTs in the SE ($M = 374$ ms) and DS ($M = 430$ ms) conditions were shorter than those in the DD condition ($M = 562$ ms). While there was no main effect for Ear, $F(1, 12) = 1.15$, $p < .31$, or Hand, $F(1, 12) < 1.0$, Hand did interact significantly with Condition, $F(2, 24) = 3.41$, $p < .05$. Post hoc analysis revealed that participants moved fastest with the right hand only in the SE.

As with the analysis of RT, when the errorful trials were removed from the data set the effect sizes were enhanced. Specifically, while the main effects for Gender, $F(1, 12) = 14.25$, $p < .005$, and Condition, $F(2, 24) = 28.57$, $p < .0001$, were repeated, there was also a main effect for Ear, $F(1, 12) = 8.15$, $p < .05$. As with the Ear X Condition interaction for RT, there was a REA for MT in the DD condition only, $F(2, 24) = 6.13$, $p < .01$.

Individual Success Rates

Success rates were calculated by taking the number of correct responses made per

Table 2.
Mean Reaction Time (ms) and Movement Time (ms) of the correct-only trials as a function of Gender, Ear, Hand, and Condition.

Gender	Left Ear		Right Ear	
Condition	Left Hand	Right Hand	Left Hand	Right Hand
Reaction Time				
Males				
Single Ear	296	308	303	333
Dichotic Same	413	429	397	404
Dichotic Different	516	491	439	408
Females				
Single Ear	366	358	348	358
Dichotic Same	441	458	438	436
Dichotic Different	648	565	603	521
Movement Time				
Males				
Single Ear	154	137	155	145
Dichotic Same	177	181	176	165
Dichotic Different	312	301	225	226
Females				
Single Ear	238	235	248	219
Dichotic Same	258	253	279	263
Dichotic Different	353	429	321	304

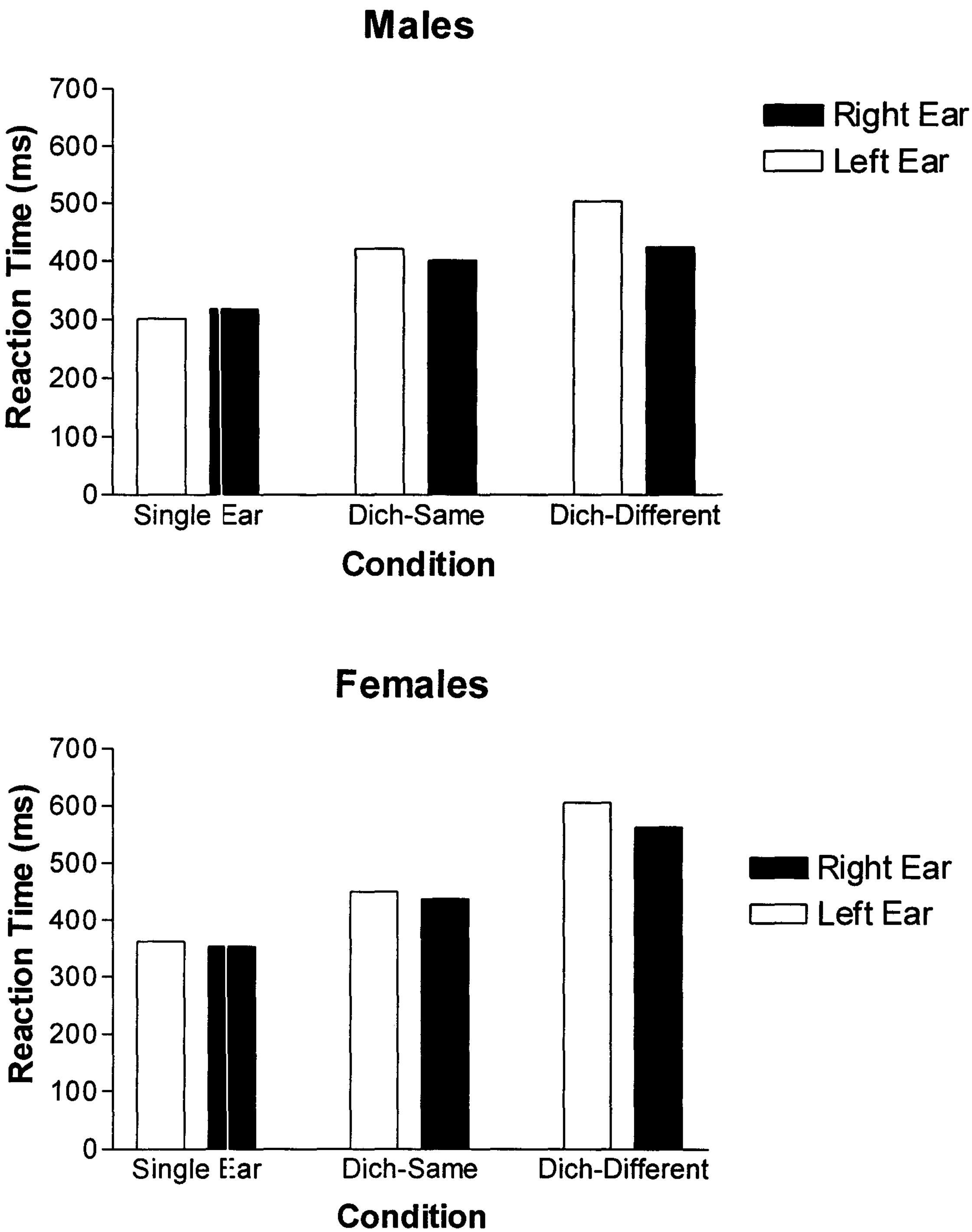


Figure 4. Reaction time (ms) of the correct only trials as a function of Gender, Attended Ear, and Condition.

ear and subtracting that number from the total number of opportunities (24) and then dividing that number by the total number of opportunities. Overall, participants were 38.69 % more successful when concentrating on their right ear (M = 84.2 %) than on their left ear (M = 45.53 %). However, during this analysis, it was recognized that one participant, a female, actually was more successful while attending to her left ear (79.17 %) than her right ear (50 %). All 13 other participants were at least 20.8 % more successful when concentrating on their right ear.

Another interesting phenomenon which was noticed through an examination of the individual results was that three of the participants, two females and one male, appeared to fall into a response set in the DD condition when responding to the information presented to their left ear. Specifically, regardless of the target for that trial, the participant always went to one of the targets. For example, one of these individuals, in the left ear DD condition moved to the "green" target 22 of the 24 trials (correctly to the "blue" target only twice) while making no incorrect movements in the right ear DD condition. This pattern of results may be indicative of participant uncertainty when attending to the left ear and thus employing a "playing the odds" type of strategy. As no laterality index could adequately account for the use of strategies, laterality indices were not calculated.

Discussion

On the basis of clinical evidence, it has been suggested that 95.5 % of the population is left hemisphere specialized for speech perception (Segalowitz & Bryden, 1983). Thus far, however, most studies utilizing the dichotic listening paradigm have produced results that tend to underestimate that percentage. These underestimations could be the result of methodologies that may allow things other than functional differences between the hemispheres to mediate laterality effects. The results of the present study suggest that this new adaptation of the dichotic listening paradigm is very sensitive to cerebral specialization for speech perception. As all participants displayed at least a 20.83 % ear advantage for correct responses, with 13 of 14 demonstrating a REA and the other demonstrating a LEA, it seems that the effects are robust.

This procedure may be more effective than the traditional dichotic listening procedures at identifying hemispheric specialization for speech perception for a couple of reasons. First, by instructing the participant to focus attention on one ear, attentional biases are reduced. Second, because the responses are immediate, any memory and report-order biases are eliminated. This is not to say that strategies do not affect outcomes, only that their effects are minimized compared to other dichotic listening procedures.

To elucidate, when auditory signals are presented dichotically, the information is projected to the contralateral hemispheres. In the majority of the right-handed population, that means that the information presented to the right ear has "direct" access to the areas specialized for the processing of speech sounds (Kimura, 1967). Thus, because the information presented to the right ear was received and decoded first, this information has primacy for response programming. This primacy, in consort with the emphasis placed on the speed of the response, more often than not, resulted in the right ear information being the basis for the programming of the response, whether the right ear was the target ear or not. Further, because the right ear information need not be transmitted via the corpus callosum, there is a far greater chance that the left ear information may be lost or degraded before being received by the processing centres in the left hemisphere. Thus, the information presented to the right ear not only has a temporal advantage, but it may also be less degraded than the information presented to the left ear. Metaphorically speaking, if there was a race between the two pieces of information for activation, the information presented to the left ear not only has longer to run, but, as a result of this less direct route, also has a greater opportunity to get lost or tripped along the route, thus giving the right ear information an advantage. This notion is supported by the RT data. Specifically, the REA for RT in the DD condition when errors were removed was 62 ms.

Although all the predictions for ear advantages were found, error and temporal interactions between Ear and Hands in the DD condition were not. Consistent with the manual asymmetry literature, there were two right hand advantages found in the present study; a RT advantage in the DD condition of the correct-trial analysis and a MT advantage in the SE condition. While the right hand RT advantage in DD was predicted, the MT advantage in the SE condition necessitates an explanation. Because changes in MT can be associated with differences in strategy, this pattern of results logically follows. Specifically, in the SE condition, because the participants did not have to be concerned with conflicting information, they could be more certain about their responses and thus move faster.

The pattern of gender differences in the present study demonstrates how differences in strategy can affect laterality results obtained in dichotic listening procedures. There are two parts to the puzzle. Initially, an examination of the error data and the RT collapsed across all the trials, that revealed that the males had a larger REA for both dependent variables than the females, would suggest that the females in the study were not as lateralized as the males. The interaction between Gender, Ear, and Condition present in the all-trial analysis, however, disappeared when the data on which movement errors were made were removed from the analysis. As, based on the pathways of information transmission, errors are more likely to occur on trials with short RTs (see above), the finding that the differences between the genders disappeared when the analysis was only performed on the longer, correct RTs, suggests then that the females were trading off speed for accuracy. However, this strategy was not completely successful. Although the females did have significantly fewer errors based on left ear information than the males, they also had an increased number of right ear errors. This increase in right ear errors, presumably caused by the extra time taken to ensure a correct response, may have resulted in both right and left ear information arriving in the processing centres concurrently resulting in more left ear intrusions.

In sum, the results of the present study suggest that this new adaptation of the dichotic listening paradigm is very sensitive to cerebral specialization for speech perception. Although, the predicted interactions involving the motor response system were not found, perhaps the nature of the motor response, low emphasis on accuracy (Elliott & Chua, 1996) and a degree of uncertainty about the spatial location of the movement (Carson et al., 1995), may have washed out any advantages the right hand/left hemisphere may have enjoyed.

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Author Notes

This research was co-funded by the National Down Syndrome Society (NDSS) and the National Institute of Child Health and Human Development (NICHD), NIH # 1 R01 HD37448-01. The author would like to express his gratitude to Lorne Tulk for the software and technical assistance in creating the audio files and to John Moroz for developing the apparatus to support this work.

Footnotes

1. Pilot testing revealed that when the DD files were blocked together, the participants would tend to adopt a strategy in which, regardless of ear they were instructed to attend to, they would always concentrate on the right ear. Thus, when instructed to attend to the left ear, they would concentrate on their right ear and then move to the opposite target. This allowed them to decrease error rates to nearly zero by ignoring the instructions. Thus, in order to ensure that the subjects were truly paying attention to the target ear, DS files were randomly mixed with the DD files.

2. Due to the large number of ERs some participants committed in certain conditions, the means in these cases represented the average across only one or two trials. Thus, in order to assess the effects of possible outliers on the means used in this analysis, a secondary analysis was performed on the medians. The pattern of results were identical, thus the analyses of the means are reported here.

Section III

Cerebral Specialization and Adaptive Strategies in a Dichotic Movement Task in Adults with and without Down Syndrome

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Abstract

A model of cerebral organization in individuals with Down syndrome (DS) has been proposed in which the main tenet is that the area that plays a dominant role in speech perception is atypically specialized to the right hemisphere (Chua, Weeks, & Elliott, 1996). Although this model has not been tested directly, there are a number of studies in which participants with DS demonstrate verbal-motor difficulties relative to their peers with and without developmental handicaps (DH) providing indirect support for this model. Recently, an adaptation of the dichotic listening procedure has been developed which is very sensitive to cerebral specialization for speech perception. The present study employed this new technique in order to test the model of cerebral organization in persons with DS proposed by Elliott and colleagues. Participants (adults with DS and their peers with and without DH) were required to move as quickly as possible to one of two colour-coded targets following verbal information presented via headphones. There were three conditions of cue word presentation: 1) monaural, (e.g., "green" in one ear and a blank track in the other); 2) dichotic-same (e.g., "green" in both ears); and, 3) dichotic-different (e.g., "green" in one ear and "blue" in the other). Results indicate that, although all three groups demonstrated a right ear advantage, the pattern of this advantage suggests that the participants were utilizing an adaptive strategy (Latash & Anson, 1996) to overcome their atypical cerebral organization. Thus, the results suggest that perhaps the pattern of laterality in persons with DS is context dependent (Tannock, Kershner, & Oliver, 1984).

Cerebral Specialization and Adaptive Strategies in a Dichotic Movement Task in Adults with and without Down Syndrome

While individuals with Down syndrome (DS) are able to perform movements based on visual information as well as their peers with undifferentiated developmental handicaps (UnDH), they have relative difficulties executing these same movements based on verbal or auditory information. These difficulties have been found for learning a sequence of movements (Elliott, Gray, & Weeks, 1991), for planning movements based on verbal precue information (Le Clair & Elliott, 1995), on auditory simple reaction time tasks (Davis, Sparrow, & Ward, 1991; Hermelin, 1964), and when performing rapid aiming movements (Welsh & Elliott, 1999c).

Elliott and colleagues have suggested that these difficulties may be related to atypical cerebral specialization. According to their model of cerebral organization, the brains of individuals with DS are organized in a manner similar to persons from the general population, except that the area for speech perception is specialized to the right hemisphere. This model is based on the finding that while people with DS show typical specialization for movement tasks, such as finger tapping (Elliott, 1985) and speech production (Elliott, Edwards, Weeks, Lindley, & Carnahan, 1987; Heath & Elliott, in press; Piccirilli, D'Alessandro, Mazzi, Sciarma, & Testa, 1991), and some perceptual tasks, such as spatial processing (Elliott, Pollock, Chua, & Weeks, 1995), they typically show a left ear advantage (LEA) instead of a right ear advantage (REA) for speech perception (Hartley, 1981; Pipe, 1983; see also Elliott, Weeks, & Chua, 1994). The model holds that a dissociation between the cerebral areas responsible for speech perception (right hemisphere) and those areas involved in the organization and control of movement (left hemisphere) may be responsible for the verbal-motor difficulties observed in individuals with DS (see Figure 1).

Although Elliott and colleagues have examined speech perception and movement organization independently, as well as verbal-motor integration using a variety of tasks (see Chua et al., 1996 for a review), they have not examined lateralized language and motor effects in the same task. Recently, Jancke and Steinmetz (1994) developed a variation of the dichotic listening procedure that holds some promise for examining the integration of verbal and motor information. These investigators presented non-handicapped participants dichotic consonant-vowel pairs and instructed them to press a button with a cued hand when they perceived a target syllable presented to one of their ears. They reported that 89% of the right-handed and 63% of the left-handed participants exhibited a right ear/left hemisphere advantage. These percentages are very similar to estimates of cerebral specialization for speech perception using other methodologies (see Bryden, 1988).

While the Jancke and Steinmetz (1994) reaction time procedure appears to be slightly more robust than verbal report dichotic protocols, it does suffer from some of the same problems inherent in the free recall dichotic paradigm. Specifically, participants could show a right ear advantage because they typically focus their attention toward their dominant side/ear. As with the free recall procedure, this failure to consider any lateralized bias confounds asymmetries due to differential processing capabilities and attentional strategy.

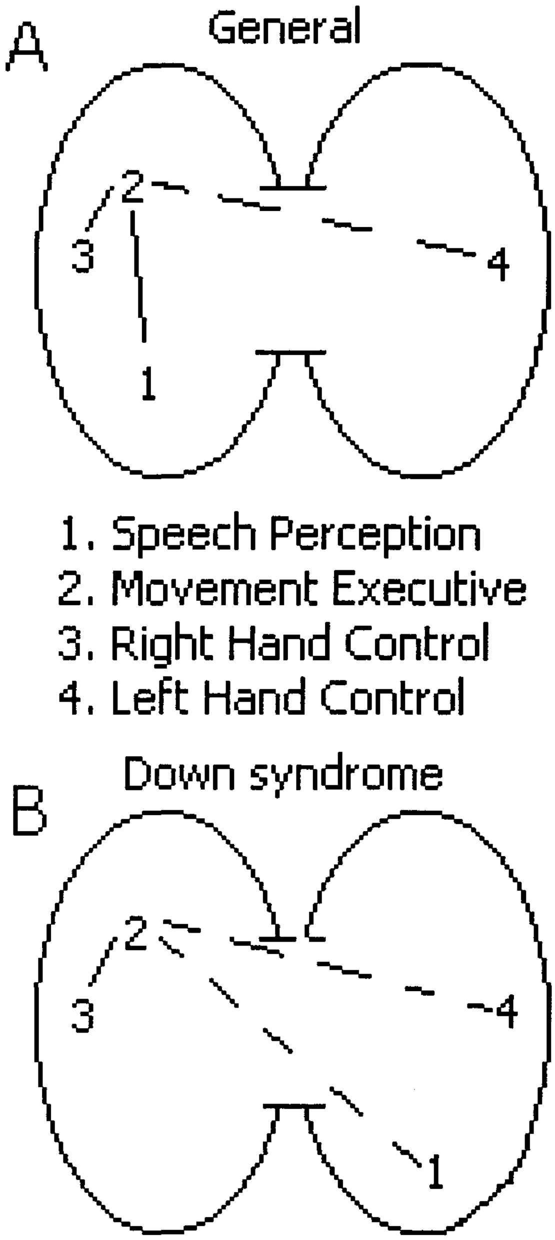

Figure 1. Diagrammatic representation of the current model of cerebral specialization for movement organization and speech perception in a right-handed individual without handicaps (A) and a right-handed individual with Down syndrome (B).

In order to avoid these "strategic" pitfalls, we employed a protocol that combines selective dichotic listening (Hiscock & Kinsbourne, 1977) with a rapid choice reaction time and movement task (Welsh & Elliott, 1999a). This new methodology allows us to not only examine lateralized ear and hand asymmetries, but also the within- and between-hemisphere interaction of the cerebral areas responsible for speech perception and limb control. By examining individuals with and without DS with this new methodology, we were able to test Elliott and colleagues' model of biological dissociation in a more direct manner than has been possible in past research (see Heath, Elliott, Weeks, & Chua, in press).

Participants were presented verbal information, either monaurally or dichotically, and were required to focus their attention on the information presented to one of their ears and then to make a rapid aiming movement to the target cued in that ear. By employing this similar, but more sensitive, task specific predictions were made. For the right-handed individuals from the average population, because their centres for speech perception and for organization and initiation of goal-directed movement are both specialized to the left-hemisphere, it would follow that information presented to the right ear, intended for the programming of a right handed movement would facilitate the quickest reaction times. Reaction times will be quickest due to the short functional distance between the two centres (see Figure 2A.2). Alternatively, when information is presented to the left ear for the programming of movements made by the left hand, due to the crossing and recrossing of the corpus callosum, reaction time should be the longest (see Figure 2A.3) (Jancke & Steinmetz, 1994).

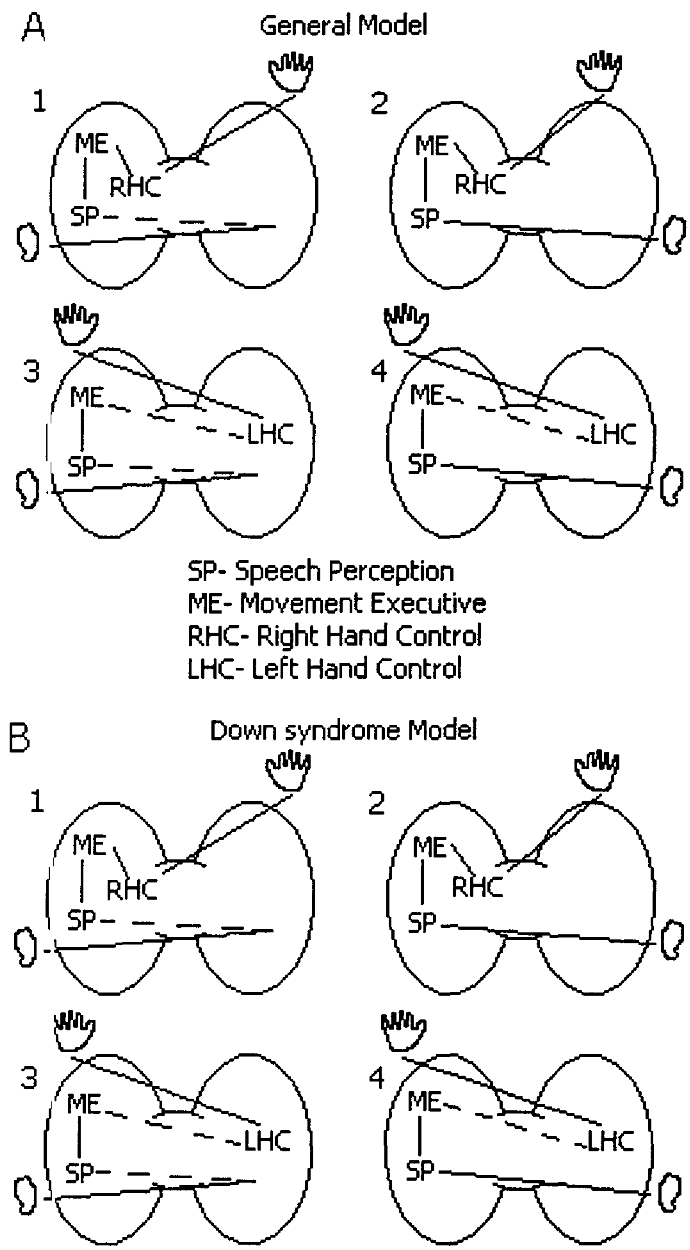

Figure 2. Diagrammatic representation of predicted paths of intra- and interhemispheric information transfer for the participants with and without undifferentiated developmental handicaps (A) and the participants with Down syndrome (B) across the four conditions. The conditions are: 1) left ear presentation, right hand movement; 2) right ear presentation, right hand movement; 3) left ear presentation, left hand movement; and, 4) right ear presentation, left hand movement. (Solid line indicates direct links between areas. Dashed line indicates transmission through corpus callosum).

Welsh and Elliott (1999a) found that, while no manual asymmetries were demonstrated, all non-handicapped participants demonstrated a strong REA for correct responses (mean errors were 7.3 per 12 trials while attending to the left ear versus 1.5 when right ear was attended). Further, following the predictions, group data revealed that a REA was also apparent for RT. This REA was enhanced when only the correct trials were analyzed. Although the performance predictions, in regard to manual asymmetries, were not bourne out, the new adaptation of the dichotic listening paradigm seems to be a powerful tool for identifying hemispheric specialization for speech perception. Thus, in an attempt to make a more direct test of the model of biologic dissociation, the methodology developed by Welsh and Elliott (1999a) was applied to those with DS.

While the performance predictions for those from the average population and those with UnDH are fairly straightforward (a REA for both correct responses and RT) performance predictions for the individuals with DS become a little more complicated. If the model of biological dissociation is correct, then due to intra- and interhemispheric communication time delays, information presented to the left ear for a right hand movement should elicit the shortest RTs with the fewest errors. Alternatively, the right ear-left hand combination may produce the longest RTs and the greatest number of errors (see Figure 2B).

Methods

Participants

There were three groups in this study. One of the groups consisted of 13 adults with Down syndrome (mean chronological age (CA) of 30.3 years and mean mental age

(MA) of 6.9 years). The 14 participants with UnDH that made up the another group had a similar CA (28.8 years) and MA (9.2 years) to those in the group with DS. The individuals from these first two groups were recruited from the Dundas Learning Centre and the Etobicoke E.T.S. The final group consisted of 14 individuals from the McMaster University community who had a similar CA (27.6 years) to the other groups (Table 1). The adults with DS and UnDH involved in this study, except one female with DS and one male with UnDH, were also involved in another study (Welsh & Elliott, 1999c). Also, the data from 6 individuals without handicaps from another study (Welsh & Elliott, 1999b) were also used in this study. The data from these participants were chosen based on their chronological age in an attempt to achieve a control group of similar chronological age to the group of participants with DS.

For inclusion in the study, each participant was required to meet the following criteria: 1) right-handedness; 2) normal or corrected-to-normal vision; 3) the ability to distinguish between the colours "blue" and "green" based on verbal presentation of the colour word; and, 4) no more than a 5 dB difference between the two ears in the threshold sensitivity and a minimum of 40 dB threshold at the frequencies of 500 Hz, 750 Hz, 1000 Hz, 2000 Hz, 3000 Hz, and 4000 Hz as determined by pure tone audiometry. All individuals were compensated for their time. Of the 52 people that were screened, 11 individuals were excluded from the study due to their failure to meet one or more of the four inclusion criteria (7 people were identified as being left-handed and 4 were excluded for having hearing impairments).

Table 1.
Group Characteristics Including Number, Gender, and Mean and Standard Deviations () of Chronological and Mental Age (years).

Group	Number	Gender	Chronological Age	Mental Age
Non-Handicapped	14	8 males, 6 females	27.6 (3.8)	-
Undifferentiated DH	14	7 males, 7 females	28.9 (4.2)	9.2 (1.7)
Down syndrome	13	8 males, 5 females	29.3 (5.5)	7.0 (1.8)

Note. Mental age was not assessed in the participants without handicaps.

Apparatus and Task

The movement environment included three coloured buttons arranged in a line embedded in a black metal surface (30 cm X 43 cm). The starting location, a 1.5 cm diameter yellow button, was located in the centre of the board. The two targets, one blue and one green translucent plastic button (1.5 cm diameter), were located 16 cm on either side of and in line with the start position.

Subjects were cued to the target locations through specially created audio files of a male voice speaking the colour words of the target buttons (i.e., "blue" and "green"). Soundscape: SSHDR1 – Version 1:18 was used to create the files. This software allowed us to align the beginning of the words to a difference of less than 0.25 ms. There were three conditions of stimulus presentation (two control and one experimental). The three conditions were based on how the information was presented through the headphones. The first control condition, termed the single ear (SE) condition, involved information presented to one ear only (e.g., "blue" in left ear, blank track in right ear). The second control condition, termed the dichotic-same (Dich-S) condition, involved the simultaneous presentation of the same word to both left and right ears. The third, and experimental, condition was the dichotic-different (Dich-D) condition and involved the simultaneous presentation of different words to each ear (e.g., "blue" in right ear and "green" in left ear). In all conditions, similar to the selective dichotic listening procedure (Hiscock & Kinsbourne, 1977), participants were instructed to attend to one ear and then complete a movement as quickly as possible based on the information presented to the attended ear while ignoring the information presented to the other ear (Welsh & Elliott, 1999a). Participants were not told whether they moved to the correct location or not. This was to prevent any changes due to learning over the course of the study and to downplay the focus on accuracy. However, they were told at the beginning of the study, and reassured periodically throughout the study, that every other person makes mistakes while performing this task and so not to be overly concerned.

Trial initiation was self-paced. Each trial began when the experimenter said "Ready?". This was the signal to the participant indicating that he/she could initiate the trial at any time. Participants, when ready, depressed the start button which marked the beginning of a 1 to 3 s random foreperiod. Following the foreperiod, one of the two targets was signaled and the participant was required to move to the appropriate target "as quickly as possible". The next trial began with the same "Ready?" cue from the experimenter.

All stimuli originated from a Pentium-Compupartner computer with Sound Blaster AWE64 and were presented to the subject via headphones (Koss Pro/466). The computer, and start and target buttons were interfaced with a Lafayette Interval Timer (Model 63520) such that the timer started upon stimulus presentation. One bank of the timer was stopped when the participant's hand was lifted from the starting position, thus measuring reaction time. When the participant's hand was lifted from the start button, a second bank was started. This bank stopped when either of the target buttons was depressed, thus measuring movement time.

Procedure

For the individuals with DS and with UnDH, testing involved two sessions of 30-

45 min, each session being separated by at least two days. On the first day of the study, pure tone audiometry and an assessment of mental age, using the Peabody Picture Vocabulary (Form L)(PPV), was carried out. At the beginning of the second session, handedness was assessed using an adapted Bryden Handedness questionnaire (Bryden, 1977). This consisted of the assessment of the preferred hand for the performance of three tasks: 1) writing their name; 2) eating soup with a spoon; and, 3) throwing a ball. While the individuals from the general population reported their hand preference for these tasks, the individuals in the other two groups were required to demonstrate the tasks after the particular implements were placed directly in front of them along the midline of their body. For inclusion in the study, the right hand was required to be the preferred hand for each of these tasks. The final screening procedure was a colour recognition task which involved the individual pointing to blue and green circles placed in random locations on a white piece of paper among an equal number of randomly placed red and yellow circles.

For the individuals from the McMaster community, the procedures were identical except that they did not complete the PPV and that they were not asked to demonstrate handedness. These tests were performed to ensure proper matching of control participants (i.e., mental age and handedness) and to ensure that all participants possessed the ability to perform the experimental task. Following these final screening tests, the participant immediately began the experimental phase of the study.

The experimental phase of this study consisted of 12 blocks of 12 trials (this included six trials at each location for each condition). All 144 trials were completed in one session that lasted 30-50 minutes. Trials were blocked based on reacting hand and attended ear. Condition of presentation was arranged differently. SE presentation trials were blocked separately from the two dichotic presentation trials, while both Dich-S and Dich-D presentations was randomly mixed into the same blocks. The Dich-S and Dich-D information conditions were randomly mixed into the same blocks in order to ensure that subjects are maintaining their attention on the information presented to the appropriate ear. Thus, there were four blocks of SE trials (one block for each Ear/Hand combination) and eight blocks in which participants were presented information to both ears (two blocks for each Ear/Hand combination). At the beginning of each block, and periodically throughout the block, participants were told which ear to attend to and with which hand to move. Also, on the second block of each dichotic block, the headphones were switched such that the right earpiece was placed on the left ear and the left earpiece on the right ear. Finally, the location of the target was randomized within each block with the constraint that each target was used equally often. Original orientation of the earpieces and block order was counterbalanced within groups.

Dependent Measures and Data Analysis

The first analysis performed was on the number of errors made by each individual. Because there were so few errors made in the SE and Dich-S conditions (less than .5 %), the analysis was only performed on the errors made in the Dich-D condition. Further, the data from 2 participants with DS and 2 participants with UnDH were eliminated prior to this analysis for failure to complete the task as required. Specifically, these individuals fell into response sets in which they always went to same target in the Dich-D condition. Thus, for the error analysis, the sum of the number of errors made by each participant (14

Non-H, 12 with UnDH, and 11 with DS) was submitted to a 3 Group (Non-H/UnDH/DS) X 2 Ear (Right/Left) X 2 Hand (Right/Left) mixed ANOVA with repeated measures on the last two factors[1].

As the temporal effects were strongest when the errorful trials were removed (see Welsh & Elliott, 1999b), the analyses of the temporal dependent measures reported here are based on the means of the error-free data. Unfortunately, because we analyzed only error-free data, we had to eliminate 2 more participants with DS and 2 more with UnDH. Their data were eliminated from the analysis because in certain conditions they never moved to the correct target, and thus, had no data to enter into the analysis. To assess differences in brain specialization, mean reaction time (RT) and movement time (MT) of the error-free trials for the remaining participants (14 Non-H, 10 with UnDH, and 9 with DS) were submitted to a 3 Group (Non-H/UnDH/DS) X 2 Ear (Right/Left) X 2 Hand (Right/Left) X 3 Condition (SE/Dich-S/Dich-D) mixed ANOVA with repeated measures on the last three factors. Post hoc analyses of all significant effects were performed using Tukey's HSD ($\alpha = .05$).

Results

Errors

Although the analysis approached traditional levels of significance (F (2, 34) = 3.12, $p = .057$), there was no main effect for Group. However, adults with developmental handicaps tended to commit more errors than the adults without handicaps. Further, while this effect was not reliable, recall that four people with handicaps were eliminated because of their inability to perform the task properly.

Of theoretical interest was the main effect for Ear ($\underline{F}$ (1, 34) = 16.34, $\underline{p}$ < .0005). As is evident from Table 2, the right ear information intruded on the left ear target information more often than vice versa. This main effect is qualified by a significant Ear X Hand interaction ($\underline{F}$ (1, 34) = 4.69, $\underline{p}$ < .05) and an interaction involving Group, Ear, and Hand ($\underline{F}$ (2, 34) = 3.40, $\underline{p}$ < .05). Post hoc analysis of the three-way interaction revealed that, although each group displayed a REA for correct trials, they demonstrated slightly different patterns of results (see Figure 3). The non-handicapped group showed no effect of Hand on performance. The participants with UnDH exhibited the pattern originally predicted based on the current models of cerebral specialization. Specifically, they made the most errors when moving with their left hand based on left ear concentration and the least errors when moving with their right hand based on right ear concentration. The participants with DS did not evidence the predicted pattern of LEA. They performed best in the right ear-right hand condition and worst when moving with the right hand and concentrating on the left ear. As evident from Figure 3, individuals with DS performed best when the path of information was intrahemispheric (right ear-right hand or left ear-left hand) than when contralateral ear-hand pairings were involved (right ear-left hand or left ear-right hand).

Reaction Time

For RT, there were Main Effects for Group ($\underline{F}$ (2, 30) = 11.42, $\underline{p}$ <.0005) and Condition ($\underline{F}$ (2, 60) = 35.77, $\underline{p}$ < .0001). Post hoc analysis of the Group effect revealed that, while the non-handicapped group had the shortest RTs, the other two groups did not

Table 2.
Mean Number of Movement Errors as a function of Group, Ear, Hand, and Condition.

Group / Condition	Left Ear		Right Ear	
	Left Hand	Right Hand	Left Hand	Right Hand
Movement Errors				
Non-Handicapped				
Single Ear	0	0.1	0	0
Dichotic Same	0.1	0.1	0.1	0
Dichotic Different	5.4	5.5	3.0	2.9
Undifferentiated DH				
Single Ear	0	0.2	0.1	0
Dichotic Same	0	0.1	0.3	0.1
Dichotic Different	7.0	6.5	4.4	3.8
Down syndrome				
Single Ear	0	0	0	0
Dichotic Same	0	0	0.1	0
Dichotic Different	6.0	7.1	6.0	3.3

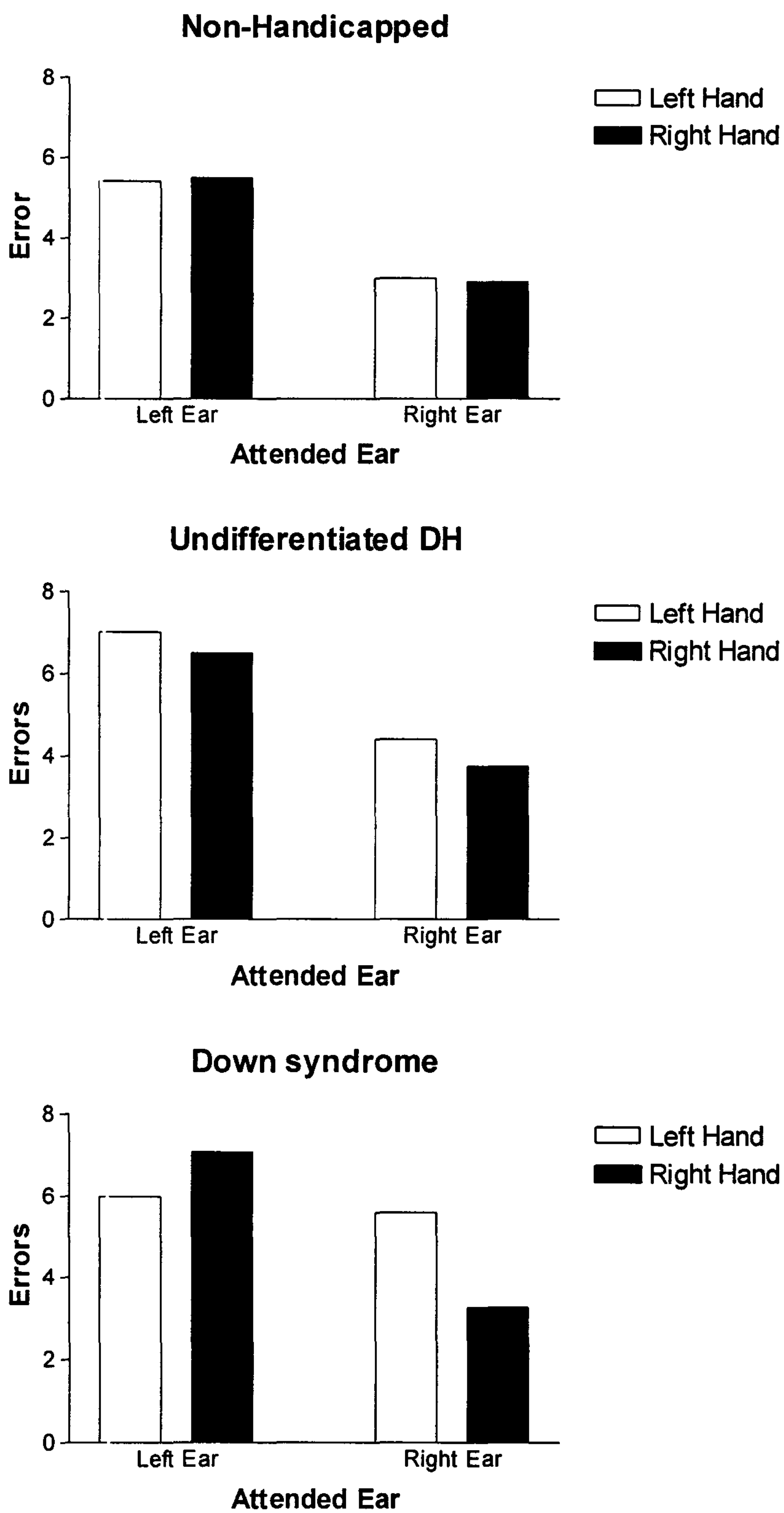

Figure 3. Total number of movement errors as a function of Group, Attended Ear and Hand.

differ. The post hoc analysis of the effect for Condition revealed that the RTs to the Dich-D were significantly longer than the two control conditions (SE and Dich-S), which did not differ. While, as in Welsh and Elliott (1999a), there was no main effect for Hand ($F = 1.42$, $p = .24$), there was a Group X Hand interaction ($F(2, 30) = 5.1$, $p < .05$). Post hoc analysis revealed that the participants with UnDH reacted sooner when moving with the left hand. There were no manual asymmetries found in the other two groups (see Table 3).

Although there was no Main Effect for Ear ($F(1, 30) = 3.76$, $p = .062$), there were significant interactions between Ear and Condition ($F(2, 60) = 4.00$, $p < .05$), Group, Ear, and Condition ($F(4, 60) = 2.76$, $p < .05$), and Group, Ear, Hand, and Condition ($F(4, 60) = 2.81$, $p < .05$). Post hoc analysis of the Ear X Condition interaction revealed that there was a REA only in the Dich-D condition. Interestingly, the analysis of the three-way interaction revealed that, contrary to our predictions, the REA for the Dich-D condition task was only present in the group with DS. Further, the adults with DS actually showed an LEA in the SE condition. Neither of the other groups showed any advantage in any condition.

The post hoc analysis of the four-way interaction revealed that the participants without handicaps did not show any ear and/or hand advantages within each presentation condition.[2] Similarly, the RTs of the participants with UnDH in the SE condition were not different across pairings. However, in the Dich-S and Dich-D conditions they actually had shorter RTs when reacting with the left hand to right ear information than in any of the other pairings. The participants with DS, again, showed a much different

Table 3.
Mean Reaction Time (ms), and Movement Time (ms) as a function of Group, Ear, Hand, and Condition.

Group	Left Ear		Right Ear	
Condition	Left Hand	Right Hand	Left Hand	Right Hand
Reaction Time				
Non-Handicapped				
Single Ear	296	290	306	307
Dichotic Same	367	394	383	372
Dichotic Different	474	452	484	427
Undifferentiated DH				
Single Ear	480	548	475	473
Dichotic Same	516	508	468	546
Dichotic Different	600	606	531	659
Down syndrome				
Single Ear	482	498	561	510
Dichotic Same	495	488	478	472
Dichotic Different	626	614	556	528
Movement Time				
Non-Handicapped				
Single Ear	168	163	177	161
Dichotic Same	183	190	188	184
Dichotic Different	309	315	251	237
Undifferentiated DH				
Single Ear	745	777	747	659
Dichotic Same	738	715	751	706
Dichotic Different	991	920	921	971
Down syndrome				
Single Ear	751	721	770	723
Dichotic Same	800	767	717	783
Dichotic Different	809	765	829	778

pattern. Unlike their pattern of errors, the adults with DS showed a REA for RT regardless of the hand used in responding. Interestingly though, in the SE condition, when the adults with DS were moving with the left hand, they reacted sooner when focusing on the left ear, than on the right ear (see Figure 4).

Movement Time

In MT, there was a main effect for Group ($F(2, 30) = 29.69$, $p < .0001$) and for Condition ($F(2, 60) = 14.57$, $p < .0001$). Like the results for RT, the participants without handicaps had shorter MTs than the other two groups, which were not different. The effect for Condition in MT was also identical to the effect in RT in that the MTs to the SE and Dich-S condition were not different from each other, but shorter than the MTs to the Dich-D presentation. No other effect or interaction reached any level close to traditional levels of significance.

Discussion

Previous research has indicated that individuals with DS show an atypical cerebral specialization for the perception of speech sounds (see Elliott et al., 1994). This finding was originally believed to reflect a complete reversal in cerebral organization (Hartley, 1981). Recently, after a number of neuropsychological studies, it has been proposed that the reversed cerebral organization is restricted to the area specialized for speech perception (see Chua et al., 1996). While the results of the present study do not support this model, a close examination of the results indicates that the adults with DS may be employing an adaptive strategy to organize and control movements.

As in our earlier study (Welsh & Elliott, 1999a), the adults without handicaps

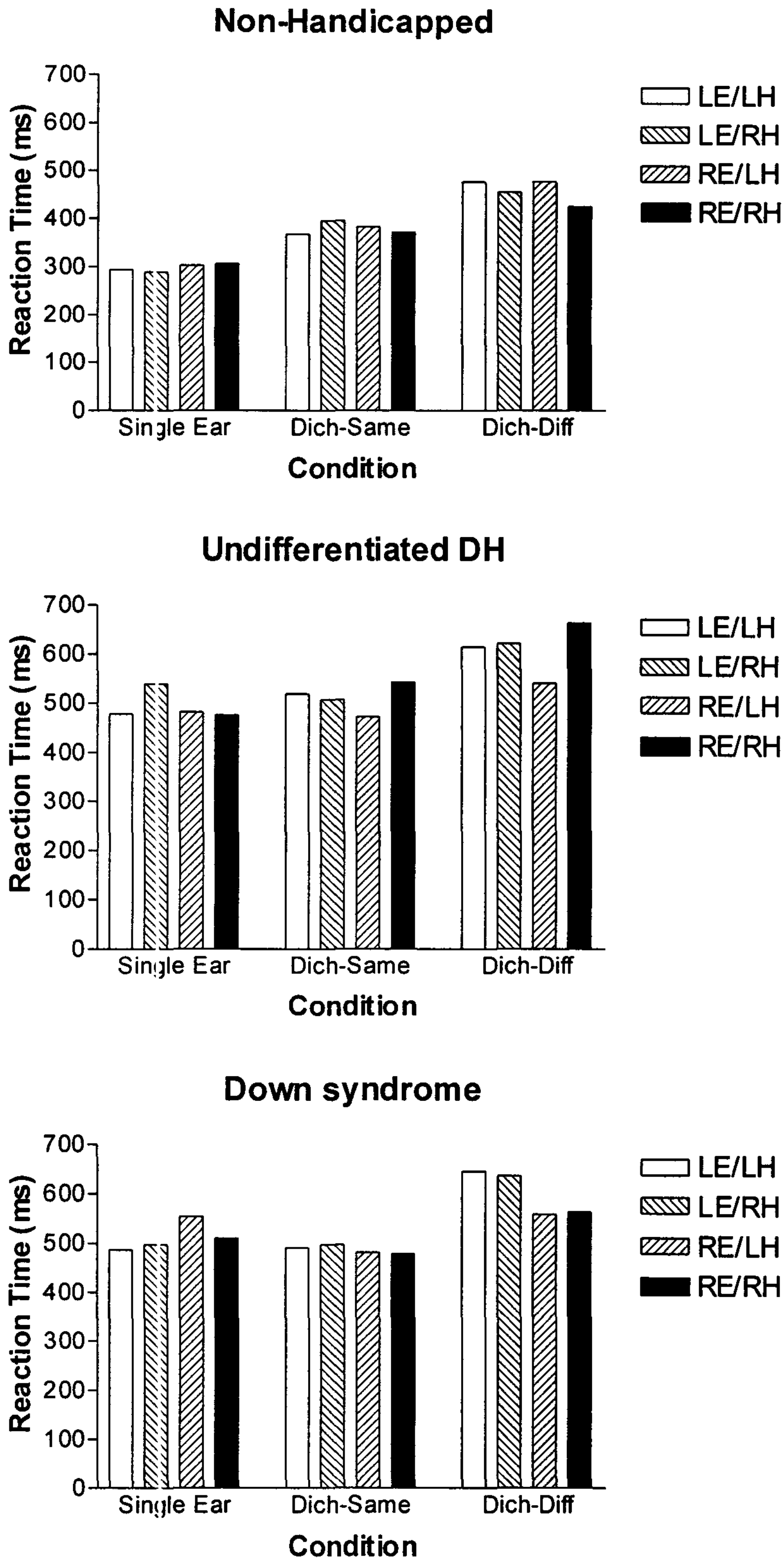

Figure 4. Reaction time (ms) as a function of Group, Attended Ear and Hand.

demonstrated a REA for both RT and selection of the appropriate target. This result was attributed to the dominant role the left hemisphere plays in both speech perception and movement organization in most right-handed individuals. It is assumed that the two stimuli, received simultaneously, are in a "race" for response activation. Because the right ear information has direct access to the area specialized for speech perception (the first leg in the race), the response activated by that information has a greater probability of winning the race. The advantage of this "head-start" is evident in the shorter RTs in right ear trials (see Footnote 2) and greater right ear intrusion into the response when participants were asked to pay attention to the left ear (see Welsh & Elliott, 1999b for a more detailed explanation).

For the other two groups, as evidenced by the high error rates and the number of participants who were simply unable to complete the task, it can be seen that the individuals with handicaps had a difficult time distinguishing the right and left ear signals. While the persons with UnDH demonstrated the pattern of results for errors originally predicted for the neurologically normal population, the RT data are more difficult to interpret. Although we have no case information on each individual, it can be assumed that the adults with UnDH are mentally handicapped for a variety of reasons. Perhaps it is not surprising that the RT findings follow no predictable pattern in this neurologically heterogeneous group.

While the individuals with DS did not show the predicted LEA for correct trials and RT, their pattern of results was different from their peers with and without handicaps and those predicted for the general population. Our findings still suggest that cerebral specialization for speech perception in this group may be atypical. The explanation of the findings is based on two assumptions. The first assumption is that the earlier research that looked at cerebral specialization for speech perception in persons with DS was done correctly. The second assumption is that, although one hemisphere may be better able at performing a particular task, both hemispheres have the capability of performing most tasks (e.g., Jones & Elliott, 1988).

It is possible that the discrepancy between the data reported here, and findings from ordinary dichotic protocols may be explained by distinguishing cerebral ability from cerebral dominance and the process of metacontrol which facilitates task performance (Levy & Trevarthen, 1976; see Hellige, 1991 for a review). The notion is that, although one hemisphere is better able to perform a particular task, both hemispheres have the ability to perform most tasks and that the hemisphere that plays a dominant role in the performance of a particular task depends on the specific constraints involved. Metacontrol, then, would refer to the neural mechanisms, perhaps an unconscious central nervous system (CNS) imposed strategy, that organize the cerebral contributions of the two hemispheres to the performance of a task. This process may require the less able hemisphere to make a greater contribution to the task than the hemisphere with the greater ability. This idea of metacontrol, in combination with the "race" model of response activation (Welsh & Elliott, 1999b), can be applied to the pattern of results found for the individuals with DS.

Specifically, while individuals with DS initiated movements more quickly and committed fewer errors when attending to the right ear, regardless of hand, they also exhibited superior accuracy when the task involved same hand-ear pairings (i.e., right ear-right hand, left ear-left hand). Presumably these pairings involve more intrahemispheric, as opposed to interhemispheric communication between the perceptual and motor areas. In persons with DS, within-hemisphere processing may entail adaptive advantages (see Latash & Anson, 1996) because of the thinner than average corpus callosum, especially in the rostral fifth (Wang, Doherty, Hesselink, & Bellugi, 1992), the area associated with semantic communication (Gazzaniga, Kutas, Van Petten, & Fendrich, 1989; Sidtis, Volpe, Holtzman, Wilson, & Gazzaniga, 1981).

The REA for RT in persons with DS (cf. Elliott et al., 1994) may have occurred because, although the left hemisphere is less proficient at processing the speech sounds, it has more direct access to the area specialized for movement planning which is located within the same hemisphere. Thus, although the final outcome of the movement has the potential of being incorrect, the movement is initiated sooner than if it is based on right hemisphere perceptual and motor processing. If similar reasoning is applied to findings involving the other pairings, the pattern of results logically follows.

Because of the dominant role the left hemisphere plays in movement organization and the relatively poorer interhemispheric semantic communication in individuals with DS, the motor planning areas would receive the information from the left hemisphere speech processing centres first, and plan movements quickly on that basis. This reliance on the left hemisphere for the processing of these speech sounds would occur inspite of the fact that the right hemisphere may process speech perception more accurately, and presumably more quickly when the motor demands of the task are low. The same type of process can be used to explain the results of the right hand-left ear pairing. That is, although the response should be based on left ear information, the within hemisphere advantage associated with the decoding of speech sounds and movement planning results in a large number of right ear intrusion errors. The fact that the adults with DS had longer left ear RTs and more correct left ear movements (M = 4.9) than left ear intrusions into right ear movements (M = 3.3) provides evidence that they may have been unsuccessfully attempting to override the preferred CNS strategy.

Before detailing the explanation for the final two pairings, right ear-left hand and left ear-left hand, it should be noted that the error rates of these pairings are very close or identical to chance. That is, assuming that you would get 50% of the movements correct by chance, the adults with DS made an average of 5.6 errors out of 12 trials in the right ear-left hand pairing and 6 errors out of 12 trials in the left ear-left hand pairing which was essentially no better than chance.

Again, assuming that both hemispheres are able, though not equally, to both decode speech sounds and program movements for the contralateral hand, then the pattern of RTs and of errors follow. Specifically, because the information presented to the right ear would have a more "direct" route to the dominant motor planning centres, the response plan, based on the weaker left hemisphere's interpretation of the speech sounds, would be sent to the right hemisphere for dispersal to the contralateral musculature. Thus, the left hand response to the right ear presentation would be initiated relatively sooner than one based on left ear presentation.

While the above explanation resolves the RT data, the movement error results need a little more explanation. To elucidate, because the response plan sent from the movement executive will be received by the right hemisphere for relay to the contralateral limb fairly quickly and, because the right hemisphere is less efficient at programming movements, the two opposing responses may arrive for activation at approximately the same time. Thus, the target that the participant moves to is a matter of chance. Because this same order of events also occurs with a left ear-left hand pairing, the same pattern of results was obtained. However, in this situation, response initiation was relatively delayed because the system was trying to perform the task as instructed.

Thus, although each hemisphere is better able to perform these tasks separately (right hemisphere for speech perception and left hemisphere for movement organization), when they have to work together in an attempt to complete this task, they essentially wash each other's advantage out and the system chooses the next best strategy (i.e., guessing. In this way, the performance of the adults with DS can be seen as adaptive and strategic based on their specific neurological differences, which their CNS has had a life time of experience to develop (see Latash & Anson, 1996).

While the explanation above resolves the conflicting results of the present study and the previous studies that employed other dichotic listening procedures, there is an alternative interpretations of the data. Similar to what Kinsbourne (1970) suggested about all dichotic procedures, the REA for the adults with DS, and indeed in the other two groups, could be due to an overall priming of the left hemisphere regardless of the ear/hand pairing. This left hemispheric priming may have resulted from the complex response requirements of the task. Both individuals with and without DS may have been influenced by this priming. To elucidate, because the left hemisphere has a dominant role in the planning of the movement, the right ear/right hand/left hemisphere system may have been attentionally primed. This priming may have then facilitated the relatively faster and accurate response initiation. While this explanation may explain the RT data, it does not account for the chance level of correct responses when responding in the right ear/left hand condition (i.e., the adults with DS would have demonstrated the same pattern of errors as their peers without handicaps). Further, Welsh and Elliott (1999b), employing an identical technique, found that one right-handed individual demonstrated a distinct left ear advantage for responding correctly. Therefore, if the hemispheric-priming explanation were correct all participants in both studies would have demonstrated a REA. Finally, as there are also studies which have shown that persons with DS have no ear advantage for speech perception (Bowler, Cufflin, & Kiernan, 1985; Parlow, Kinsbourne, & Spencer, 1996; Tannock et al., 1984). Thus, as Tannock et al. (1984) suggest, the laterality for speech perception demonstrated by individuals with DS may be context and task specific. Thus, the task employed in the present study may require cerebral communication that overrides any advantages a particular cerebral hemisphere may enjoy.

In sum, although we replicated our findings of a REA for speech perception in adults without handicaps on a verbal-motor task which combines dichotic listening with a rapid choice aiming task, the adults with developmental handicaps found the task to be very challenging and did not demonstrate the predicted patterns. Despite the difficulty they had with this task, both groups with and without DS demonstrated a reliable REA. While this result is surprising given the literature on language in individuals with DS which suggests atypical cerebral specialization for speech perception (Hartley, 1981; Pipe, 1983; Elliott et al., 1994), when the results are examined employing a metacontrol and adaptive strategy point of view, the results are congruent with the work of Tannock et al. (1984) who suggest that laterality effects in persons with DS may be context specific (see also Bowler et al., 1985). Future research will attempt to determine the relative contributions of strategy to the phenomenon of verbal-motor difficulties in individuals with Down syndrome. Further, to better understand how the movement requirements of our task impacts on the perception of speech sounds, future research will compare the laterality findings on our task to those of more traditional dichotic listening methodologies.

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Author Notes

This research was co-funded by the National Down Syndrome Society (NDSS) and the National Institute of Child Health and Human Development (NICHD), NIH # 1 R01 HD37448-01. The author would like to extend a warm thank you to all those at the Dundas Learning Centre and the Toronto Association of Community Living who made this study possible. I would specifically like to thank Ann Pearson, Agnes Samler, Lorry Cumming, Shelia Magee, and all the staff at the Etobicoke E.T.S. and the Dundas Learning Centre who helped us with this study. The author would also like to thank John Moroz for his technical support in the construction of the apparatus, Lorne Tulk for his help in the creation of the audio files used in this study, and Chris Watson for his help in data collection.

Footnotes

1. Although Welsh and Elliott (1999b) found differences between the genders in this task, Gender was not included as a factor due to the small number of females with DS (3) in the final analysis. Also, initially in all these analysis, Location was added as an extra factor. However, because there were no effects for Location, it was subsequently dropped from the analysis. Because for some participants in some conditions, the elimination of error trials resulted in having very few trials to average, an analysis was also performed on the medians. This analysis revealed near identical results, thus the analysis of the mean data is reported here. Finally, while the two groups of adults with handicaps were significantly different in MA (t (21) = 3.83, p <.001), when the data were reanalyzed using MA as a covariate, the results did not change.

2. Although there was no REA for RT for the adults without handicaps, this was mainly the result of the increased variability due to the participants in the other two groups. A separate 2 Ear X 2 Hand X 3 Condition repeated measures ANOVA was performed on the non-handicapped group's data only. Post hoc analysis of the three-way interaction (F (2, 26) = 3.47, p < .05) revealed that the RTs in right ear/right hand combination were shorter than any other pairing. The other pairings were not different. Thus, there was an REA for the group without handicaps (see Welsh & Elliott, 1999b).

Epilogue

Elliott and colleagues have proposed that, while, for most functions, the brains of individuals with Down syndrome (DS) are organized in a manner similar to their counterparts without handicaps, the area that plays a dominant role in speech perception is atypically specialized to the right hemisphere (see Chua, Weeks, & Elliott, 1996). Thus, the area specialized for speech perception (right hemisphere) is dissociated from the areas specialized for the organization and control of movement (left hemisphere). This model of brain organization has been used to explain the verbal-motor difficulties demonstrated by individuals with DS relative to their peers with and without developmental handicaps (DH). These verbal-motor difficulties have been observed in performing a sequence of movements (Elliott, Weeks, & Gray, 1990), learning a sequence of movements (Elliott, Gray, & Weeks, 1991), and preprogramming movements based on precue information (Le Clair & Elliott, 1995). Though these studies have provided some indirect evidence for the model of biological dissociation, a direct testing of the model has yet to be conducted. The purpose of the three studies contained within this thesis was to replicate the findings of verbal-motor differences and then develop and apply a new neuropsychological technique that would be able to test the model of biological dissociation more directly.

The first study was an attempt to replicate and extend the findings of Davis, Sparrow, and Ward (1991) and Hermelin (1964) that persons with DS have an auditory specific information processing difficulty in comparison to their peers with and without DH. Thus, choice reaction times (RTs) and movement times (MTs) of these three groups were compared under three different stimulus conditions: 1) direct visual mapping condition for which the target itself illuminated; 2) indirect visual mapping condition for which a non-target light illuminated which cued the participant to the similarly coloured target; and, 3) verbal condition for which the participant was presented the colour word of the target (i.e., "blue") via head phones. Results indicated that, although RTs of the two groups with DH were equivalent across all conditions, the participants with DS had longer movement times in the verbal condition than in either of the two visual conditions; a pattern not demonstrated in either of the other two groups. Thus, the findings of the first study provide additional indirect support for the model of biological dissociation.

In the second study, a new adaptation of the dichotic listening procedure was introduced. This new adaptation proved to be more sensitive in identifying cerebral specialization speech perception than the traditional dichotic listening procedures. This new technique was essentially the combination of the selective dichotic listening procedure (Hiscock & Kinsbourne, 1977) with a rapid choice aiming task. Because the new technique contained a movement component, it was hoped that the new technique would also be sensitive to lateralization for movement organization. Based on the current models of cerebral specialization in the general population, specific predictions were made. It was predicted that when the participants moved with their right hand based on target information presented to their right ear, movement errors, RTs, and possibly MTs would be minimized. In opposition to the right ear-right hand pairing, the left ear-left hand pairing would result in the longest RTs and MTs and the most movement errors. Also of interest in this study were possible gender differences in lateralization. Results revealed that, although no manual asymmetries were found, participants showed right ear advantages for both RT and correct responding. Further, the findings indicate that findings of gender differences in lateralization in previous studies (for example, Lake & Bryden, 1976) may be the result of differing strategic approaches to the task rather than differences in laterality. Overall, the results indicated that the new adaptation of the dichotic listening procedure was very sensitive to lateralization for speech perception.

Because this new technique had been very successful at assessing cerebral lateralization for speech perception in the general population, the purpose of the third study was to employ this new technique in an attempt to perform a more direct testing of the model of biological dissociation. Performance predictions for the two groups with and without DH were identical to those of the previous study. Specifically, that both of these groups would show a right ear advantage for RT, MT, and correct responding. Predictions for the adults with DS were that they would demonstrate left ear advantages for these same dependent measures. Contrary to these predictions, adults with DS showed a right ear advantage for this task. The pattern of results, however, suggests that they may have been employing an adaptive strategy in an attempt to maximize task performance despite an atypical cerebral organization (Latash & Anson, 1996). Thus, the results provide support for the hypothesis of Tannock, Kershner, and Oliver (1984) that functional laterality in this population may be context dependent.

In summary, the results of the three studies provide indirect evidence of functional differences between individuals with and without DS. While the first study provides more evidence that people with DS have relative difficulties in organizing movements based on verbal information, results of the third study failed to support the model of biological dissociation.

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