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The effect of visual, verbal, and auditory instruction on motor performance and learning for persons with Down syndrome

by

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Dedication

This paper is dedicated to my wife Kim and son Carsten. Kim, you are the love of my life and I couldn't imagine surviving this process without your love and support. You have always been there for me throughout this long and sometimes arduous journey; whether it was bringing me pizza and coffee in the lab at midnight or giving me an ultimatum when I needed it. You are the one thing in my life that has never changed and the one person I can always count on. Carsten, you are my inspiration and the reason behind everything I do. Your smiling face every day when I returned home kept me going when I thought I had nothing left.

Abstract

Participants with Down syndrome (DS) as well as typically developing peers matched for mental and chronological age completed a 3-step movement sequence in response to visual (lights), verbal (spoken word), meaningful auditory (music), and non-meaningful auditory (tones) instructions. Results indicate that participants with DS demonstrated slower reaction time in the visual condition but were more consistent in their movement time and made fewer errors suggesting they adopted a strategy in which they traded speed for accuracy. Further, they were slowest, most variable, and made the most errors in the non-meaningful auditory condition indicating that the amount of meaning associated with the method of instruction is an important determinant of motor performance. These results support the assertion that motor performance for persons with DS is determined in part by the unique pattern of cerebral lateralization for this population while at the same time demonstrating the importance of task and stimulus familiarity.

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Table of Contents

List of Tables

List of Figures

Abbreviations

CA	Chronological age match
CC	Corpus callosum
DLT	Dichotic listening task
DS	Down syndrome
fMRI	Functional magnetic resonance imaging
LEA	Left ear advantage
LH	Left-handed
MA	Mental age match
MEG	Magnetoencephalography
MT	Movement time
NRH	Non-right handed
REA	Right ear advantage
RH	Right-handed
RT	Reaction time
sdMT	Standard deviation of movement time
TD	Typically developing
TT	Total time
UnDD	Undifferentiated developmental delay

I. Introduction

Purpose

The purpose of this study is twofold. The first, and primary, purpose is to examine the effect of auditory instruction on motor performance and learning for persons with Down syndrome (DS). The second is to examine whether the meaningfulness of that auditory information further affects motor learning. Auditory information, simply, is information extracted through audition that is non-verbal in nature (i.e. sounds but not words). Auditory instruction, then, is the presentation of non-verbal auditory information that allows for successful completion of a given task. Auditory instruction as it relates to perceptual motor behaviour for persons with DS will be discussed relative to the model of biological dissociation first reported by Elliott, Weeks, and Elliott in 1987.

Significance of Study

Evidence of verbal-motor deficits for persons with DS (Maraj, Bonertz, Kivi, Furler, Ringenbach, & Mulvey, 2007) has been well documented over the past 30 years. However, until 1987 when Elliott and colleagues first introduced their model of biological dissociation, there was no empirically supported theoretical framework to explain this phenomenon. Briefly, the model of biological dissociation states that in the non-DS population, both speech perception and movement production are lateralized in the left hemisphere, thus the two centres can communicate easily on verbal-motor tasks. In the DS population, however, speech perception is atypically lateralized in the right hemisphere while movement production remains typically lateralized in the left hemisphere. As a result, verbal-motor tasks necessitate communication between the hemispheres for persons with DS; this interhemispheric communication both delays and degrades the motor response. While this model has fuelled much of the research in this area (Maraj et al., 2007) it remains somewhat limited in its scope. While persons with DS consistently demonstrate a verbal-motor deficit and visual-motor advantage in motor performance and learning tasks, the results regarding auditory information are unclear.

While not completely omitted in the literature, there are few studies examining motor learning, despite the fact that it is often a more meaningful assessment than motor performance (Elliott, Gray, & Weeks, 1991; Maraj, Li, Hillman, Jeansonne, & Ringenbach, 2003; Meegan, Maraj, Weeks, & Chua, 2006). The relatively permanent change in behaviour that results from motor learning is often a more desired result when compared to one time performance of a skill. Persons with intellectual and physical disabilities need to have more focus put on learning and less on performance, as it is the former that will provide the greatest benefit to their quality of life. Replication and performance are too often the focus but provide the least in the way of reward. Moreover, the need for practical implications outside of the laboratory is more likely to result from a measure that is more applicable to the real world.

Auditory stimuli are a valuable source of information in everyday life. In fact, many messages that require immediate action and universal understanding are communicated in this manner (Ringenbach, Allen, Chung, & Jung, 2006). Sirens on emergency vehicles, a car horn, a referee’s whistle, fire alarms, and buzzers on timers are all examples of auditory signals with which everyone is familiar. Information is communicated quickly and easily regardless of verbal ability and without visual attention. Such a source of pertinent information has great potential for persons with DS. While research has consistently demonstrated that visual demonstration results in superior performance and learning on a variety of motor tasks and that verbal instruction results in a deficit, due to atypical cerebral lateralization and callosal morphology (Maraj et al., 2007), the former is not always a viable option. Recent results (Ringenbach, Chua, Maraj, Kao, & Weeks, 2002; Ringenbach et al, 2006; Robertson, Van Gemmert, & Maraj, 2002), however, suggest that for certain tasks auditory instruction may be a viable alternative to either visual or verbal instruction. Unfortunately, while a search of the literature shows methodical, systematic research regarding both visual and verbal instruction for persons with DS, the same cannot be said regarding auditory instruction.

For the most part, auditory instruction has been ignored until recently and the few studies that have been conducted suffer from a lack of congruence with respect to the model of biological dissociation. Currently, Ringenbach and her colleagues (Ringenbach et al., 2002, Ringenbach et al., 2006; Robertson et al., 2002) are the only researchers systematically studying auditory instruction as it relates to motor performance for persons with DS. However, this line of research has focused primarily on coordination measures for continuous, bimanual tasks while the bulk of the literature with respect to the model of biological dissociation has focused on response times and movement errors for discrete and serial unimanual tasks. The disconnection between recent studies focusing on auditory instruction and earlier studies focusing on visual and verbal instruction results in a conceptual gap in the literature. This study, therefore, is an attempt to return to the basic principles of the model of biological dissociation in order to provide a more congruent picture of how auditory instruction relates to visual and verbal instruction.

Further, while few would argue that visual or verbal instructions are inherently meaningful and therefore effective in their ability to convey information, auditory information may be more abstract. Vision is known as ‘the master sense’ and visual information often takes precedence over competing information from the other senses (Sekuler & Blake, 1994). Likewise, speech and language are the dominant forms of human communication and remain the foundation of interpersonal interaction. Sound is much more abstract than either vision or language and therefore requires a greater degree of interpretation and association. As a result, this study will examine the level of meaning associated with different types of auditory instruction and compare them with the established techniques of visual and verbal instruction.

Delimitations

Participants were adolescents and young adults with DS as well as typically developing (TD) peers matched for chronological and mental age. All participants were volunteers recruited from the Edmonton Down Syndrome Society, the University of Alberta community, and through colleagues, associates, and parents known to the experimenter from his work with Children’s Autism

Services of Edmonton. Independent variables are mode of instruction (visual, verbal, meaningful auditory, and non-meaningful auditory) and block (acquisition 1, acquisition 2, and retention). The dependent variables measured are reaction time (RT), movement time (MT), standard deviation of movement time (sdMT), total time (TT), and errors.

Limitations

The first and most important limitation is that lateralization varies among individuals within any population. This lack of homogeneity is closely related to, but not mutually exclusive to, handedness. Looking first at TD individuals, evidence suggests that non-right handed (NRH) individuals are more variable in their cerebral lateralization than their right-handed (RH) counterparts. According to Bryden, Hėcaen, and DeAgostini (1983), in the TD RH population, 87.2% of individuals are left hemisphere lateralized for language with the remainder being right hemisphere lateralized. In the TD left-handed (LH) population, however, 61.9% of individuals are left hemisphere lateralized for language and 15.5% are right hemisphere lateralized. In the remaining 22.6% of TD LH individuals, language appears bilaterally represented.

For individuals with DS this lack of homogeneity for lateralization is even more apparent due to an increased occurrence of non-right handedness. For the DS population, estimates of non-right handedness vary from 25 to 50% (Opitz & Gilbert-Barness, 1990; Soper, Satz, Orsini, Van Gorp, & Green, 1987); substantially higher than 10% of NRH individuals within the TD population. Further complicating this disparity in handedness is the suggestion by Bishop

(1990) that within the DS population there is a significant proportion that is neither RH nor LH but display mixed handedness.

Together, increased variability of language lateralization of LH individuals combined with the increased prevalence of NRH individuals within the DS population has lead most researchers to test RH participants exclusively. Handedness, as it relates to lateralization, appears to be a confounding factor that introduces participant variability into the research design. The effects of this variability, currently, cannot be accounted for. Unfortunately, controlling for handedness by testing only RH sample participants is not representative of the entire population. Right handed and NRH persons with DS who are lateralized similar to those who are RH, account for the majority of the DS population and for that reason the exclusion of NRH participants is justifiable, although not ideal, in studies of lateralization.

The second important limitation is that motor learning is not observable; it must be inferred through changes in skill performance (Rose, 1997). The same is true with respect to the model (Elliott, Weeks, et al., 1987, Elliott & Weeks, 1993), as it is only a theoretical explanation of the verbal-motor behaviour for persons with DS. Therefore, we are not testing lateralization, the process whereby functions come to be located primarily on one side of the brain (Kolb & Whishaw, 1998), per se, but rather motor skill. Whether the performance of verbal- and/or visual-motor skill is due to lateralization, in whole or in part, cannot be stated with absolute confidence. However, lateralization may provide a good explanation of the observed behaviour. The behaviour needs an underlying rationale or framework in order to study it; the model provides that but no more.

Lastly, samples are never truly representative of the overall population. Volunteers tend to vary from the greater population. Most often they are highly motivated, have higher levels of education (in this particular case they may be higher functioning/higher mental age), female, and more confident. Further complicating this issue is that due to their intellectual disability, volunteers with DS will also require parental/guardian consent for participation.

II. Review of Literature

Down syndrome is both the most prevalent chromosomal abnormality and the most frequently recognized cause of intellectual impairment (Selikowitz, 1997). It occurs in all races and cultures and in both males and females. Named after Dr. John Langdon Haydon Down, who first described the unique set of physical features common to individuals with the syndrome in 1866, it was not until 1959 when Lejeune, Gautier, and Turpin demonstrated the genetic cause of DS (Opitz & Gilbert-Barness, 1990; Selikowitz, 1997). All cases of DS result from at least a partial, extra copy of the 21st chromosome, consequently individuals with DS have 47 chromosomes instead of the usual 46 (Selikowitz, 1997). There are three distinct types, or forms of DS: Trisomy 21, translocation, and mosaicism. Trisomy 21 is the result of a complete third copy of the 21st chromosome in every cell in the body and accounts for approximately 95% of all cases. The cause of this non-disjunction remains unknown. Translocation is the result of an extra portion, as opposed to a complete copy, of the 21st chromosome and accounts for approximately 4% of cases. Mosaicism is similar, in kind, to Trisomy 21 in that there is a complete extra copy of chromosome 21, but in mosaicism this occurs only in some of the bodies cells, not all (Selikowitz, 1997).

Deficits in verbal-motor behaviour for persons with DS have long been known but were not systematically and empirically studied until the latter part of the 1970's (See Maraj et al., 2007 for a detailed review). Initial exploration began using dichotic listening tasks (DLT) first described by Kimura in 1967. Later, results of manual asymmetry and dual task interference studies led Elliott and colleagues to postulate their model of biological dissociation (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993). This model has served as the driving force and theoretical framework for much of the research that followed.

Dichotic Listening Tasks

Based on the pivotal work of Doreen Kimura (1967), DLT have been used as a non-invasive method of determining cerebral lateralization, especially as it relates to language. In her seminal study, Kimura found that when participants were presented with different words to each ear simultaneously via headphones, they reported hearing the word presented to the ear opposite the hemisphere lateralized for language. Specifically, most participants displayed a right ear advantage (REA) for DLT corresponding to typical left hemisphere lateralization for language. According to Kimura, each ear has both ipsilateral and contralateral projections; however, the contralateral pathway is larger and faster. The resulting temporal advantage is further aided by central competition. Together, the temporal advantage and central inhibition combine to occlude information from the ipsilateral pathway and so information from the contralateral pathway is reported.

Although Kimura's technique is widely accepted as a behavioural means to determine language laterality, it is worth noting that it was three and a half decades later that Hund-Georgiadis, Lex, Friederici, and von Cramon (2002) verified the technique using modern neuro-imaging techniques. The researchers assessed language lateralization using both DLT and functional magnetic resonance imaging (fMRI) and discovered a high degree of agreement between the two measures. Specifically, DLT and fMRI resulted in similar assessments of language lateralization in 97.1% of cases.

Initial attempts to apply DLT to the study of DS, however, appeared contrary to those of Kimura as researchers reported an atypical left ear advantage (LEA) for participants, corresponding to right hemisphere lateralization for language (Anderson & Barry, 1975; Reinhart, 1976; Zekulin-Hartley, 1978; as cited in Hartley, 1981). However, the application of DLT to this population was in its infancy and it remained unclear whether this pattern of atypical lateralization was biologically inherent or the result of cognitive development. Hartley (1981) attempted to answer this question by testing children between the ages of 3 and 6 and confirmed the atypical LEA for participants with DS and typical REA for their age matched comparisons. Based on the young developmental and chronological age of her subjects, Hartley argued that atypical language lateralization was due to biology not development (1981).

Based upon the existing literature and the results of her previous study, Hartley proposed a simple model of reversed cerebral organization for persons with DS in 1982. According to Hartley, “the two hemispheres are characterized by different types of processing, that is, basically holistic, parallel, simultaneous processing in the right hemisphere and serial, analytic, sequential in the left hemisphere” (Hartley, 1982, p. 263). It follows, then, that reversed, right hemisphere lateralization for language demonstrated by participants with DS may be representative of a switch in the above dichotomy (Hartley, 1982).

Following Hartley’s theory of reversed cerebral specialization, two studies expanded the field of cerebral lateralization beyond DLT. First, Pipe (1983) confirmed a LEA for persons with DS, along with a REA for those with undifferentiated developmental delay (UnDD) and those who were TD. Further, the strength of the ear advantage was stronger for DLT following extensive auditory discrimination training (Pipe, 1983). Then, Hartley (1985) confirmed the LEA for persons with DS while, more importantly, also demonstrating a deficit in a verbal-motor task but not a corresponding deficit in a visual-motor task compared to participants with UnDD. This distinction is central to the model of biological dissociation proposed by Elliott and colleagues two years later.

With multiple studies demonstrating and confirming an atypical LEA for persons with DS, other aspects of laterality became of primary interest. Using

Hartley's (1982) model of reversed cerebral specialization as a backdrop, the next two years saw a plethora of laterality research for persons with DS.

Manual Asymmetry

Manual asymmetry studies are based on the idea that hand differences for certain motor tasks are correlated to hemispheric information processing (Elliott, Weeks, et al., 1987). Elliott and colleagues argued that in the TD population, the left hemisphere appears to be dominant for sequential processing. The right hand, then, has an advantage in performing this type of task. In contrast, the right hemisphere appears to be dominant in tasks requiring spatial skills, with the left hand having an advantage in performing this type of task. If the simple model of reversed cerebral specialization (Hartley, 1982) is correct, persons with DS should exhibit the opposite pattern from that described above (Elliott, Weeks, et al., 1987).

A couple of studies looked at manual asymmetry and reported results contrary to the expectations of Hartley's (1982) model of reversed cerebral specialization for persons with DS. Both, Elliott (1985) and Elliott, Weeks, and Jones (1986), found that the pattern of both frequency and variability during finger tapping tasks was similar to their peers with UnDD and those who were TD. Therefore, while persons with DS appear atypically lateralized for language, they remain typically left hemisphere lateralized for sequential movement (Elliott, 1985; Elliott et al., 1986).

Dual Task Interference

The premise behind dual task interference is that two competing tasks will interfere with each other more if they are subserved by the same hemisphere than if they are controlled by separate hemispheres. Elliott, Edwards, Weeks, Lindley, and Carnahan (1987) tested this theory by having RH participants tap, continuously, with both their right and left index fingers while also repeating words presented by the experimenter. They found that right-hand finger tapping was disrupted for the male participants with DS and that finger tapping with both hands was disrupted for the female participants with DS. The authors attributed the disruption in right-hand finger tapping for male participants with DS to interference resulting from left hemisphere lateralization of both movement production and speech production. The disruption in finger tapping for both hands for the female participants with DS was never adequately explained (Elliott, Edwards, et al., 1987).

Biological Dissociation Model

Attempting to create a model that encompassed mounting evidence contrary to the model of reversed cerebral specialization (Hartley, 1982), Elliott and colleagues postulated their model of biological dissociation in 1987. The basic tenets of the model are as follows. Within the general population, both speech perception and movement production (including speech) are lateralized in the left cerebral hemisphere. As a result, verbal-motor tasks are performed easily as both centres can ‘communicate’ easily with one another. Within the DS population, however, there is a functional dissociation with speech perception atypically lateralized in the right hemisphere while movement production remains typically lateralized in the left hemisphere. Verbal-motor tasks, therefore, require interhemispheric communication in order to be executed. This interhemispheric communication results in both a temporal disadvantage as well as lost or degraded information. See Appendix A for a pictorial representation of the model.

Beyond the Basics

Evidence gathered from DLT, manual asymmetry, and dual task interference studies thus far had lead Elliott and colleagues to conclude that Hartley's (1982) theory of reversed cerebral specialization was untenable. The same evidence that cast serious doubt as to Hartley's (1982) theory also served as the foundation for their new paradigm, the model of biological dissociation (Elliott, Weeks, et al., 1987). However promising the Elliott, Weeks, et al. (1987) model was, it still needed to stand up to rigorous scientific testing; the results of which would either support and strengthen the model or, conversely, disprove it.

One of the strongest pieces of evidence in support of the model of biological dissociation was by Elliott, Weeks, and Gray (1990). The authors used verbal and visual cueing to study its' effect on performance of a motor sequence. They found that participants with DS had more difficulty performing a sequence of movements based on verbal instruction than a single movement. There was no such difficulty translating visual instruction into a movement sequence. According to the authors, the deficit resulting from the dissociation of speech perception and movement production in the DS brain is amplified in a sequence of movements compared to a single movement (Elliott et al., 1990). A single movement requires interhemispheric communication between centres responsible for speech perception and movement production only once. As the number of movements increases, the amount of interhemispheric communication increases in kind. Therefore, the more complex a movement is, the greater the verbal-motor deficit for persons with DS.

Results of the previous study demonstrated that the degree to which persons with DS display a verbal-motor deficit is due, at least in part, to the amount of interhemispheric communication required to perform the task (Elliott et al., 1990). It follows, then, that the corpus callosum, the conduit through which this communication takes place, may be a significant factor in the verbal-motor deficit unique to this population. This is exactly what Wang, Doherty, Hesselink, and Bellugi demonstrated in 1992. The researchers used MRI to show that the corpus callosum of persons with DS is structurally different from those with Williams syndrome and those who were TD. The authors found that participants with DS had a corpus callosum that was smaller rostrally and overall more rounded than either of the comparison groups. The rostral fifth having previously been shown to be made up of projections from the frontal cortex that, in turn, had previously been shown to be smaller in persons with DS (Wang et al., 1992). With respect to the model of biological dissociation, the syndrome specific pattern of cerebral lateralization necessitates interhemispheric communication on verbal-motor tasks. This interhemispheric communication delays and degrades the motor response in its own right, but is further compromised by an inferior corpus callosum unique to this population.

Returning to the idea of cueing, Le Clair and Elliott (1995) demonstrated that persons with DS demonstrate a verbal-motor deficit of the time of exposure. Given advance information, both visually and verbally, participants with DS showed no difference in reaction time (RT) in response to either stimuli compared to their peers with UnDD. They did, however, exhibit much longer movement time (MT) in the verbal condition but not the visual condition, suggesting that persons with DS attempt to use advance, verbal information in order to perform a movement but are unable to do so compared to their peers. The inability of these participants to utilize advance information in an attempt to compensate for the verbal-motor deficit highlights its biological origins.

Until 1993, the lexicon of the model of biological dissociation had only described persons as being either left or right hemisphere lateralized for various processes. However, that changed when Elliott and Weeks used a DLT to calculate a laterality index for speech perception. This index could then be used to plot laterality along a continuum, with ear advantage being seen more as a matter of degree (Elliott & Weeks, 1993b). The authors found that there was a significant relationship between their newly created laterality index and verbal-motor deficiencies on the apraxia battery. Moreover, participants with DS who exhibited the largest LEA for speech perception had relatively more difficulty performing movements based on verbal instruction when compared to visual. Not only was there evidence to suggest that there are varying degrees to which persons with DS can be right hemisphere lateralized for speech perception, but also that the degree to which a person is atypically lateralized corresponds to their level of verbal-motor impairment.

Motor Learning versus Performance

Within the body of literature only three studies examine motor learning; the remainder examine motor performance. The distinction between the two is not a minor one, as motor performance relates to one time performance of a skill while motor learning relates to a relatively permanent change in an individual’s capability to perform a skill over time (Rose, 1997). While learning is a more practical outcome than performance in many scenarios, it is especially true for a population with intellectual and physical disabilities who have relatively greater difficulty in this regard compared to their peers. Motor skills such as writing one’s name, fastening a button, or brushing one’s teeth are but a few examples of tasks that all individuals execute almost daily. Simple performance of these skills, while encouraging, is of little practical application in the day-to-day lives of persons with DS and those who support them. It is, in fact, the ability to execute skills such as these, repeatedly and over time, which provides the greatest reward for all concerned. Motor learning, it could be argued, is the pathway to independence.

The first study to examine motor learning for persons with DS was not until four years after Elliott, Weeks, et al. (1987) proposed the model of biological dissociation. According to the authors,

> “although we have suggested that this dissociation and the subsequent verbal-motor performance deficits exhibited by persons with DS may have

> implications for motor skill acquisition (Elliott, 1990; Elliott & Weeks, 1990), we have tempered our speculation about skill acquisition because conditions that affect *performance* do not always affect *learning* in the same manner" (Elliott et al., 1991, p. 211).

No longer satisfied speculating about the potential effects of the functional dissociation of speech perception and movement production on motor learning, Elliott and colleagues examined whether deficits in verbal-motor performance generalized to motor learning. Recording RT, MT, and errors, the researchers had participants with DS, UnDD, and those who were TD perform a three-step movement sequence. Acquisition trials were preceded by verbal cues stating the sequence order, retention trials were not preceded by verbal cues, and transfer trials were completed with the opposite hand. While there was no discernable difference for MT and errors, RT data demonstrated that similar levels of performance during acquisition for both participants with DS and UnDD did not remain during tests of retention and transfer. In both instances, participants with DS were slower to react relative to their peers with UnDD. The results of this study appear paradoxical. On the one hand, RT data supports the assumption that persons with DS have difficulty learning a novel motor task based on verbal instruction relative to their peers. This verbal-motor deficit for motor learning would appear to generalize from the verbal-motor deficit commonly displayed for motor performance, except that the same data fails to demonstrate any difference between participants with DS and their peers with UnDD during acquisition following verbal cues. Despite this problem, the authors argue that the results of the study provide at least partial support for the model and that further studies would be needed. Regrettably, more than a decade would pass before another study on motor learning was done.

In 2003, Maraj et al. tested the model of biological dissociation as it relates to skill acquisition, but this time examining both verbal- and visual-motor learning. Maraj and colleagues had participants with DS, UnDD, and those who were TD complete three-step movement sequences by using a mouse to move a cursor displayed on a computer screen in front of them. Half of the participants in each group were given verbal instructions while the other half were given visual instructions. Both retention and transfer tests were performed at 1 hour and 24 hour intervals following the completion of acquisition trials. Retention trials were performed exactly as the acquisition trials; while transfer trials were performed following instruction in the opposite modality (i.e., those who performed acquisition trials in the verbal condition performed transfer trials in the visual condition and vice versa). Results indicate that during acquisition, participants with DS had faster response times in the visual instruction condition and slower response times in the verbal instruction conditions relative to their peers with UnDD. Retention tests showed that the MT deficit increased for the participants with DS in the verbal condition at both 1 and 24 hour intervals. Participants with DS in the visual condition not only had faster response time and MT but this advantage carried over to transfer tests done in response to verbal instruction. Specifically, participants with DS who originally learned the motor sequences through visual instruction outperformed their peers with UnDD in the 24 hour verbal instruction transfer test, suggesting that the verbal-motor deficits experienced by persons with DS can be offset by having them first learn motor skills visually. The results of this study expand upon the predictive ability of the model of biological dissociation in two fundamental ways. The first is that the deficit that results from the functional dissociation of speech perception and movement production within the DS brain, generalizes, and amplifies, from tasks of motor performance to tasks of motor learning. The second is that persons with DS may be able to consolidate visual instruction to the extent that future exposure to verbal instruction of that same skill is unhampered; thus, highlighting the importance of appropriate initial exposure for motor skill acquisition.

The final study examining motor learning sought to build upon the positive results of the previous studies by expanding the scope of the motor skill from a single limb, upper body task to a full body, gross motor task (Meegan et al., 2006). Researchers used a combination of visual demonstration and verbal instruction to instruct participants with DS on the performance of a hop, a step, and a jump over a 4-day period. On day 5, baseline performance of each skill was assessed following a demonstration and description of each skill to be performed. On day 6, retention of each skill was assessed with half the participants following a visual demonstration, and half following a verbal description. The results indicate that, overall, participants demonstrated superior performance in the visual condition compared to the verbal condition. That is, participants displayed a higher level of developmental skill for a learned task following visual demonstration than verbal instruction. Further analysis, however, revealed that while participants in the visual group outperformed their counterparts in each of the three skills, the difference was only significant for the jump skill (the lack of statistical significance for the other two skills is most likely due to insufficient power resulting from the low number of participants in each group). Regardless, this study again demonstrates the visual-motor advantage and verbal-motor deficit for persons with DS that stems from their unique pattern of cerebral lateralization, further expanding the deficit to whole body skills.

The results of these studies suggest that not only does the verbal-motor deficit carry over from motor performance to motor learning but that this problem is exacerbated. Fortunately, the benefits of visual instruction also appear to carry over and appear to amplify as time goes on. Further, initial visual instruction offsets or negates the verbal-motor deficit during later verbal instruction. The results of motor learning research have far reaching effects, both in terms of theory as well as clinical relevance. While motor learning has rarely been studied in persons with DS, it is perhaps the largest oversight in the literature. If it is true that visual instruction results in greater benefit as time goes on regardless of whether later recall is in response to visual or verbal instructions, then perhaps initial visual instruction is a way around the verbal-motor deficit or at least a stop-gap measure. This optimism, however, must be tempered by the lack of studies examining motor learning in persons with DS combined with a lack of replication of those conducted.

Auditory Information

Until very recently, research regarding perceptual motor behaviour for persons with DS has taken the conceptual form of visual instruction is beneficial and verbal instruction is detrimental. Researchers have consistently demonstrated a verbal-motor deficit and visual-motor advantage for persons with DS compared to their peers with developmental delay not related to DS as well as those who are TD (Maraj et al., 2007). Recently, however, researchers (Ringenbach et al., 2002; Ringenbach et al., 2006; Robertson et al., 2002) have begun to investigate an alternative to the traditional forms of instruction. Evidence suggests that auditory instruction can be a useful method of conveying information regarding the execution of motor skills to persons with DS. To date, limited studies have been conducted in this area, but results thus far suggest that auditory instruction can be a viable alternative to visual or verbal instruction that has dominated much of the literature.

Ironically, the pair of studies that foreshadowed the inclusion of auditory information into the visual/verbal debate for persons with DS did not examine auditory information at all. The first study by Elliott, Pollock, Chua, and Weeks (1995) examined the consistency of right hemisphere lateralization for spatial information across modalities. In the first of two experiments, participants performed a dihaptic shape-matching task, a tactile analogue to DLT. According to the authors, right hemisphere lateralization for spatial processing should manifest in a left hand advantage for this task. However, only LH participants with DS displayed the expected left hand/right hemisphere advantage, RH participants with DS as well as their peers with UnDD displayed no hand advantage. In the second experiment, participants performed a visual field dot enumeration task. This time, all participants displayed the expected left visual field/right hemisphere advantage.

The second parallel study, by Weeks, Chua, Elliott, Lyons, and Pollock (1995) utilized similar protocols to the previous study, but with a switch in focus from spatial to language stimuli. In the first experiment, participants performed a dihaptic letter-matching task and in the second experiment, they performed a visual field letter identification task. The results of both experiments indicate right hemisphere lateralization of language stimuli. Specifically, participants with DS displayed a left hand advantage during the dihaptic letter-matching task and a left visual field advantage for the visual field letter enumeration task. This left side/right hemisphere advantage for tasks involving language supports the predictions of the model of biological dissociation by demonstrating that the atypical pattern of cerebral lateralization extends beyond speech to include language stimuli presented through other modalities as well.

Taken together, the results of the previous two studies help to both support the model of biological dissociation and expand upon it. Typical left hand/left visual field superiority for spatial tasks (Elliot et al., 1995) combined with atypical left hand/left visual field advantage for language tasks (Weeks et al., 1995) confirm the pattern of cerebral lateralization unique to the DS karyotype described by Elliott and colleagues. Further, the apparent right hemisphere lateralization of language stimuli when presented visually and tactilely, suggests that the verbal motor deficit for persons with DS is not exclusive to speech, but rather generalizes to other forms of language processing. It follows, then, that audition, which has been largely omitted in the literature due to its association with speech, should be considered as a viable modality with which to convey information.

Several years later the results of the parallel studies (Elliott et al., 1995; Weeks et al., 1995) were substantiated through the use of neuro-imaging. In 2002 Weeks, Chua, Weinberg, Elliott, and Cheyne used magnetoencephalography (MEG) to create a display of cerebral areas responsible for processing language, non-verbal auditory stimuli, and movement production. True to predictions, the researchers observed greater right hemisphere activation when the female participant with DS was reading. This pattern did not appear when the participant was exposed to the sound of a click nor during a self-initiated button press. Non-verbal auditory information resulted in bilateral activation and limb movement resulted in left hemisphere activation. The latter two results were also in accordance with the hypothesis and similar to patterns of activation for peers without DS. Real time representations of an intact, functioning DS brain confirmed the structural and functional premises of the model, namely, atypical right hemisphere lateralization of language perception but typical right hemisphere lateralization of movement production and, as argued in this study, bilateral representation of auditory information.

The results of the previous three studies not only support the model of biological dissociation (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993), but in so doing also provide the theoretical basis for the inclusion of auditory instruction into the established framework. According to Elliott and colleagues, within the DS brain only language processing is atypically lateralized, all other forms of processing remain typically lateralized with respect to their peers (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993). This pattern of lateralization is evident in the Weeks et al. (2002) study that clearly demonstrated atypical lateralization of language processing but typical lateralization of both movement production and auditory processing. Further, Elliott and colleagues and Weeks and colleagues demonstrated the stability of this paradigm across modalities in parallel studies in 1995.

If the model of biological dissociation is correct in stating that the verbal-motor disadvantage for persons with DS is due to interhemispheric communication between areas responsible for language processing in the right hemisphere and those responsible for movement production in the left hemisphere and that the visual-motor advantage is due to left hemisphere lateralization of both types of processing, it follows that bilateral processing of auditory information should result in levels of performance and learning intermediate the two. The combination of fast, efficient intrahemispheric communication with slower, degraded interhemispheric communication should result in neither an advantage nor a deficit.

While encouraging in the context of the present discussion, this assertion must be interpreted with caution as not all non-verbal auditory stimuli are processed in the same way. While Weeks et al. (2002) demonstrated bilateral processing of a click for a person with DS as well as TD peers, it is generally acknowledged that within the TD population, “rhythm and pitch discrimination are processed mainly in the left hemisphere whereas timbre and melody are found chiefly in the right.” (Jenkins, 2001, p. 170). Thus, the type of auditory processing is intrinsically linked to the type of stimuli presented, and as such this constraint must always be accounted for when discussing the inclusion of auditory information into the existing paradigm. A review of the literature, however, provides little neuro-imaging or other concrete data demonstrating the different types of auditory processing in persons with DS so we must infer the relationship from behavioural evidence. While not numerous, studies in this area seem to support the inclusion of auditory information into the existing literature on visual and verbal information while at the same time illustrating the need for further research in this domain.

When presented with either visual or verbal information, the literature has consistently demonstrated quicker response times for persons with DS following visual instruction than following verbal instruction (Le Clair & Elliott, 1995; Maraj et al., 2003). Again, according to the model of biological dissociation this visual-motor advantage is thought to reflect the processing advantage that results from left hemisphere lateralization of both visual information and movement production. Unfortunately, with the exception of the Maraj et al. (2003) study that use an auditory stimulus to signal the movement imperative (a point we will return to later in this section), none of these studies directly compares the processing time for visual, verbal, and auditory information. There is, however, one study that does provide some insight into this matter.

In 1991, a study by Davis, Sparrow, and Ward examined the effects of light, sound, and a combination of light and sound on response times for persons with DS compared to their peers. Regardless of condition, TD participants exhibited the fastest RT, followed by participants with UnDD, and finally participants with DS. Further, participants in each group were fastest in the light and sound condition, followed by the sound condition, then finally the light condition. However, the difference between the sound and the light conditions for the participants with DS was small and not significant unlike their peers whose RT significantly increased from light and sound, to sound, to light. Fractionated RT data revealed that participants with DS were significantly slower in premotor time (time from stimulus onset to muscle activation) for the light and sound condition as well as the sound condition but not for the light condition; explaining the differing results from their peers. Premotor time, the authors argue, reflects the processing component of RT tasks and accounts for the greatest variability in RT. Lastly, MT data suggests that while participants with developmental delay were slower than participants who were TD, there was no difference between participants with DS and their peers with UnDD. Despite the fact that Davis and colleagues did not mention or relate their results to the model of biological dissociation (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993), the results of this study are consistent with the model of biological dissociation by demonstrating a visual-motor advantage for persons with DS relative to their peers. While it is true that participants with DS did not perform best in the visual condition, they did perform comparatively better in this condition than did their peers, thus demonstrating an advantage unique to this population. Further, participants in this study were simply required to perform a single movement in response to a stimulus. If the visual-motor advantage for participants with DS in a simple, single step task is sufficient to negate the advantage for their peers in response to auditory stimuli, it seems logical that this advantage would be amplified as the number movements required grows. Ringenbach and colleagues explored this line of thought as it relates to continuous gross motor tasks in a series of studies.

In the first of several studies, (Robertson) Ringenbach, Van Gemmert, and Maraj (2002) investigated motor performance for a continuous task in response to visual, verbal, and auditory stimuli. With their hands occluded from sight, participants drew vertical lines simultaneously with both hands in response to either a visual (flashing lines), verbal (‘up’/’down’), or auditory (high tone /low tone) metronome. Real time tracings of their movements could be seen on a computer monitor directly in front of them. Surprisingly, and contrary to both their hypotheses and the model of biological dissociation, participants with DS performed worst in the visual condition and best in the auditory condition, with the verbal condition intermediate the two. The confounding results, the authors argued, was due to overloading in the visual condition. In this case, vision was required to both time their movements with the flashing lines of the metronome as well as monitor their line drawing performance. The reliance of both tasks on the visual system overwhelmed participants with DS already known to have lower cognitive ability and decreased attention (Robertson et al., 2002). Conversely, while verbal information is not optimal in generating a motor response, it did still provide useful information without leading to overloading. Superior performance in the auditory condition, then, the authors attributed to ability of auditory information to convey pertinent information regarding the timing of the task, but being non-verbal in nature, not resulting in interhemispheric communication and subsequently a deficit (Robertson et al., 2002).

Later that same year Ringenbach, Chua, Maraj, Kao, and Weeks (2002) continued their examination of auditory information conducting a study to determine whether it was the bimanual nature of the previous task that lead to the anomalous results. This study required the participants to draw continuous circles to either a visual (dot flash) or auditory (beep) metronome with their hands in full view. Again, participants with DS performed best in the auditory condition and worse in the visual condition. Participants with DS demonstrated this pattern of results in both unimanual and bimanual conditions, suggesting that auditory information is beneficial in either type of task (Ringenbach et al., 2002).

Several years later Ringenbach, Allen, Chung, and Jung (2006) returned to the examination of auditory information as a third option for instruction for persons with DS, but this time with what they referred to as more of a, “real-world task” (p. 30). The real-world task was drumming as, the authors argue, “research has shown that people with Down syndrome have an affinity towards music and rhythm” (p. 30). Further, the metronomes used provided more specific/meaningful information. This study, again, utilized visual, verbal, and auditory metronomes but in each condition, the information presented to the participants was purposeful. Specifically, the metronomes were: visual (image of a drumstick/drumsticks hitting a drum), verbal (‘up’/’down’), and auditory (sound of drum being hit/cymbal being hit, corresponding to down and up, respectively). Lastly, the authors divided drumming into discrete and continuous conditions to examine whether or not the continuous nature of previous tasks had affected the results. Again, the results were not as hypothesized; this time, however, they were in support of the model of biological dissociation. While the results showed no performance differences in the discrete condition, participants with DS performed best in the continuous condition with the visual metronome and worse with the verbal metronome, with auditory intermediate the two. In addition, they were more coordinated in the discrete condition compared to the continuous condition. The results of this latest study were in accordance with what would be predicted from the model of biological dissociation. According to the authors, meaningful visual information resulted in the best performance due to the direct communication between those areas responsible for spatial processing and those responsible for movement production within the left hemisphere. Meaningful verbal information resulted in the poorest performance due to interhemispheric communication between those areas responsible for language processing in the right hemisphere and those responsible for movement production in the left hemisphere. Meaningful auditory information resulted in a level of performance between the two well established extremes of visual and verbal information.

Accordingly, the authors attributed the differing results of this study to the specificity of the information in the metronomes (Ringenbach et al., 2006). While previous metronomes had been vague (flashing dots, tones, etc) and only provided temporal information about the tasks, the metronomes in this study were designed specifically to provide both temporal and spatial information and were, therefore, both more specific and more meaningful to the task at hand (Ringenbach et al., 2006).

As previously mentioned, the pattern of results that support the model of biological dissociation were exhibited only in the continuous condition; there were no significant differences in the discrete condition (Ringenbach et al., 2006). According to Elliott et al., (1990) and Ringenbach et al., (2002), the visual-motor advantage and verbal-motor deficit displayed by persons with DS is amplified as tasks progress from discrete to serial to continuous: as the number of motor outputs increases from one to infinity, the number of times that the cerebral systems responsible for language or visual processing and those responsible for movement production increases in kind. The small, but significant, verbal-motor deficit or visual-motor advantage exhibited during discrete tasks is therefore summed with each additional execution of that task, creating a larger and larger difference between the two conditions.

While it was never articulated by Ringenbach and colleagues, not only was there a change in the level of meaning associated with the auditory metronomes in her studies but also a change in the type of processing. The distinction between high and low tones is processed as pitch while the distinction between a drum beat and a cymbal being hit is processed as timbre. Recall that in the TD population pitch is thought to be processed in the left hemisphere and thus has direct access to centres responsible for movement production resulting in fast, efficient intrahemispheric processing and a subsequent performance advantage relative to verbal-motor processing. This is exactly what was demonstrated in the first 2 studies by Ringenbach and colleagues. Visual-processing should also have resulted in fast, efficient intrahemispheric processing and subsequently an advantage but did not due to due to overloading.

When the metronomes were changed to be more meaningful in the third study, the type of visual and verbal processing did not change, but the type of auditory-motor processing should have. By changing the metronomes from tones to different instruments the type of processing should have changed from pitch to timbre resulting in switch in auditory processing from the left hemisphere to right. The results with regard to auditory and verbal-motor performance did not. Moreover, visual-motor performance went from being the poorest to best. In this study not only did the type of processing change in accordance with a change in metronomes but so to did the complexity of the task and level of meaning associated with the stimuli. Together these results highlight that the complex nature of the relationships between cerebral lateralization, task complexity, and meaningfulness of information and that each can impact motor-performance for person with DS.

Although far from conclusive, evidence from studies examining auditory information as it relates to perceptual motor behaviour for persons with DS provides some justification for its’ inclusion as an alternative to the heavily studied options of visual and verbal information. Taken together, the evidence regarding non-verbal auditory instruction for persons with DS suffers most from a lack of congruence. Each study discussed previously in this section highlights an important result relative to the existing visual/verbal literature and the inclusion of auditory instruction into the existing framework. Earlier studies examining response times for discrete and serial tasks are sporadic and seem isolated within the existing literature regarding the model of biological dissociation, while the recent work by Ringenbach and colleagues, although more systematic and congruent, has focused on the timing of continuous tasks as well as measures of coordination rather than processing time. That being said, when placed in context, the studies begin to form the basis of an argument for how this third variable fits into the existing knowledge regarding perceptual motor behaviour for persons with DS.

The first important finding is that motor performance is intrinsically linked to the type of processing that occurs. The verbal-motor deficit, visual-motor advantage and varying performance of auditory-motor tasks result from the corresponding proximity of the cerebral areas associated with processing that type of information to those required to execute a motor response. While the lexicon of the model most often describes the verbal-motor deficit for persons with DS, this phraseology is misleading. It is, in fact, the processing of language information, regardless of the modality in which it is conveyed, that results in a deficit, not just the processing of speech. This generalization of the verbal-motor deficit to all forms of language processing is clearly demonstrated by the very authors of the model itself. Weeks et al. (1995) showed right hemisphere lateralization of language by demonstrating a left hand and left visual field advantage for letter recognition while Weeks et al. (2002) showed definitive evidence of right hemisphere processing while reading. The stability of right hemisphere processing of language across the modalities of vision, audition, and touch suggests that the phraseology of referring to persons as having a verbal-motor deficit is both misleading and overly limited in its' scope. Extending this argument further, if there is only an association between the modality in which information is conveyed and the type of processing that results, then auditory information may be either detrimental, as in the case of speech, or potentially helpful, as in the case of non-verbal auditory stimuli. In the context of the present discussion, then, the verbal-motor deficit is neither confined to, nor requisite to, the auditory modality, lending little credence to its' exclusion from the existing literature.

The next important finding is how motor performance guided by auditory information compares to that which is guided by visual or language information. In terms of response times, the results of Davis et al. (1991) demonstrates equivalent response times for persons with DS following auditory stimuli or visual stimuli. Participants with DS demonstrated no significant difference in reaction time between light and sound conditions despite a sound advantage for their peers. This study demonstrates quick, efficient processing of both auditory and visual information for persons with DS as well as confirming the visual-motor advantage for persons with DS (remember that in this instance the visual-motor advantage is only relative to their peers).

While the results of Davis et al. (1991) apply in some respects to the model of biological dissociation, they must be interpreted, in the context of the present discussion, in combination with the results of the visual/verbal response time results previously discussed. Maraj et al. (2003) demonstrated that when visual and verbal instructions are given, persons with DS respond significantly quicker following visual instruction. Unfortunately, in this instance experimenters used an auditory stimulus to signal the movement imperative following either visual or verbal instructions, so that while the participants were processing visual or verbal information they were, in fact, responding to auditory stimuli. The reverse can be said of Davis et al. (1991) in which the stimulus that initiated the movement imperative was manipulated following both a demonstration and explanation of the task to be executed. The disconnect between the modality in which instructions are given and the stimulus used to initiate the movement imperative make it difficult to generalize across the studies, and therefore, across the different types of information processing. Note: this confounding factor is addressed in the design of the present study. Regardless, it is fair to say that when a consistent modality of instruction is used persons with DS react equally quickly to both auditory and visual stimuli and that this represents a visual-motor advantage unique to this population. In addition, when a consistent auditory stimulus is used following differing types of instruction there is also a visual-motor advantage.

In terms of coordination and timing, the results of Ringenbach and her colleagues' studies suggest that auditory information is beneficial in a variety of circumstances. In 2002, Ringenbach and colleagues demonstrated in two separate studies that for continuous tasks that rely on visual feedback for online monitoring, auditory is the best type of information (Ringenbach et al., 2002; Robertson et al., 2002). Whether the task is unimanual or bimanual, persons with DS struggle to follow visual cues while monitoring their own movements. Processing of both tasks places a high demand on the visual system leading to overloading. Overloading, in turn, negatively affects performance to the extent that visual-motor performance is worse than both auditory-motor and even verbal-motor performance, the latter a documented deficit. It appears, then, that in cases such as these, visual information can be too much of a good thing and that auditory information is the best option.

It also appears, however, that meaningful information presented in a less contrived situation produces the pattern of results dictated by the model of biological dissociation. Specifically, Ringenbach et al. (2006) demonstrated a visual-motor advantage for continuous drumming when the information used was specific to the task and therefore meaningful. Verbal information resulted in the poorest performance with auditory information in between the two. This same visual, auditory, verbal pattern of results did not appear for the discrete task of a single drumbeat, though, suggesting that meaningful information and task appropriateness is of greater importance as the complexity of the task increases.

It is worth mentioning that while visual demonstration and verbal instruction appear inherently meaningful, it does not exclude varying levels of meaning similar to that described for auditory instruction. Specifically, Bunn, Roy, and Elliott (2007) demonstrated that for children with DS they performed significantly worse than comparison participants when asked to pantomime an action but equivalently when asked to perform the same action with the aid of a tool. The authors argue that the presence of a tool provides individuals with context to their actions, therefore reducing demand on their short term memory. So, by providing context to the motor task to be performed the experimenters created a situation in which the verbal instruction was more meaningful, enhancing performance for participants with DS.

The final step regarding the inclusion of auditory information as an alternative to visual and verbal information is its' practicality. As already discussed, the most practical application of any motor task is its' ability to generalize across different environments and over time. Unfortunately, there are no studies examining the effects of auditory instruction on motor learning for which to draw any conclusions. However, logic dictates that if the visual-motor advantage and verbal-motor deficit are amplified as the task grows in complexity (Elliott et al., 1990; Ringenbach et al., 2002) and that this advantage is magnified over time (Maraj et al., 2003), that the disparity between the two would become greater. Auditory instruction, resulting in a left hemisphere advantage, right hemisphere deficit, or bilaterally neutral should range between the increasingly polarizing extremes.

Conclusion

The literature on perceptual motor behaviour for persons with DS has repeatedly demonstrated a visual-motor advantage and verbal-motor deficit for this population relative to their peers. Dichotic listening tasks and neuro-imaging have provided evidence of atypical right hemisphere lateralization of language perception while manual asymmetry, dual task interference, and neuro-imaging have provided evidence of typical left hemisphere lateralization of sequential processing and movement production. Together, this evidence has been used first to disprove Hartley's (1982) model of reversed cerebral specialization, then to formulate and strengthen a new model of biological dissociation first proposed by Elliott and colleagues in 1987. While the model has proven to be invaluable in its contribution to the literature on visual- and verbal-motor behaviour for persons with DS it has the potential to be expanded further to the study of auditory-motor behaviour as well.

Auditory information has the potential to be a viable alternative to visual and verbal information but has rarely been studied. Within the context of the model, auditory information appears to be processed in a range of ways varying from left hemisphere to right hemisphere as well as bilaterally depending on the type of stimuli being processed. Further, while visual demonstration and verbal instruction are inherently specific and meaningful sources of information, auditory information (often operationalized as tones of different pitches) is inherently vague and open to interpretation making comparison to the others difficult at best.

The purpose of this study is to examine the effects of meaningful and non-meaningful auditory instruction on motor performance and learning within the context of the model of biological dissociation (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993). In order to bridge the gap in the literature two very important concepts must be taken into consideration. The first important concept is sequence. Specifically, while the bulk of the studies comparing visual- and verbal-motor behaviour focussed on discrete and sequential gross motor tasks, the studies comparing auditory information have been either discrete or continuous. Recall that as tasks increase from discrete to sequential to continuous the amount of processing increases resulting in larger advantages or deficits. The gap in the auditory information literature as it relates to sequences permits not comparison but speculation. The second important concept is learning. Of the studies reviewed in this proposal, only three have focused on motor learning. This oversight casts doubt on the generalizability of the model and combined with its exclusion of auditory information greatly limits its practicality.

Based on the literature and the aim of this study, the hypotheses for this study are as follows. First, it is hypothesized that participants with DS will perform best in the visual condition, followed by the meaningful and non-meaningful auditory, and finally verbal. In addition, it is hypothesized that the differences between the four conditions will increase following the retention interval.

III. Methods and Procedures

Participants

Participants for this study were 7 adolescent and young adult men and women with DS (chronological age range 16.417 – 30.917 years, *M* = 22.929; mental age range 6.417 – 10.917 years, *M* = 7.893) as well as an equal number of TD chronological age match (CA; range 17.083 – 28.833 years, *M* = 22.952 years) and mental age match (MA; range 6.0 – 8.667 years, *M* = 7.191) comparison subjects. Mental age was assumed to be the same as chronological age for all TD comparison subjects. See Table D1 in Appendix D for descriptive statistics for group equivalencies among participants. The total number of participants was 21. All protocols were submitted to the Faculty of Physical Education and Recreation, Faculty of Agricultural, Life, and Environmental Sciences, Faculty of Native Studies Research Ethics Board, University of Alberta for approval. Recruitment of all but one of the participants with DS was conducted through the Chairperson of the Board for the Edmonton Down Syndrome Society who contacted eligible candidates via email and personally at society events. One participant with DS was recruited through a network of colleagues, associates, and parents known to the experimenter from his work with Children’s Autism Services of Edmonton (an organization that offers specialized services to children and adolescents with communication disorders). Recruitment of CA and MA participants was conducted through word of mouth to family and friends and their children as well as through Children’s Autism Services of Edmonton. Information letters containing a brief description of the study’s context and aims were presented to each potential participant and their family or guardian, along with background information on the researchers and contact information (email addresses, phone numbers, and office location). Those interested in participating then notified the researcher regarding their intent via phone or email and an appointment for testing was scheduled.

Prior to participation in the study all participants, along with their parents or guardian (in the case of MA participants and participants with DS), read/or were read the participant information letter and informed consent/ascent form, which was then signed. All participants met the following criteria: 1) were right-handed, 2) had normal, or corrected-to-normal, vision, and 3) had no known hearing impairments. Visual acuity was assessed using the Snellen Visual Acuity and Colour Vision Chart. Handedness was determined using a shortened six-item handedness inventory (Oldfield, 1971) in which participants demonstrated writing with a pen, drawing a circle with a pen, cutting paper with scissors, throwing a tennis ball, eating with a spoon, and brushing their teeth. The latter two items were 'pretend'. Assessment of mental age using the Peabody Picture Vocabulary Test (3rd ed.; PPVT-III) for participants with DS followed experimental protocols to decrease motivational and attentional demands prior to testing. Mental age was considered equivalent to chronological age for all comparison participants. Hearing was assessed using a Maico 24 audiometer. See Appendix A for the specific hearing screening protocol. All assessments were mentioned as potential benefits of participation.

A within subjects design was used. Within subjects designs help in the assessment of change over time, rules out non-equivalence between groups, and lowers the number of participants required for statistically powerful analysis. The last point is particularly poignant here as DS only occurs in approximately 1 out of every 700 births (Selikowitz, 1997). Further, decreased incidence of right-handedness, reduced verbal and cognitive ability, and increased occurrence of vision and hearing impairments eliminate even more potential candidates from an already small population.

Task

Participants were required to perform an upper limb motor sequence, using a mouse to move a cursor on a computer screen directly in front of them. All trials were done with their dominant (right) hand. Seated in an adjustable office chair, the targets were arranged vertically on a computer screen, directly in front of their midline. At the bottom of the screen was the home position, represented by a circle, from which all trials began. Next closest in proximity was a whistle, followed by a trumpet, then, finally, a bell. See Figure C1 in Appendix C for a visual representation of the computer display. Starting from the home position there were three distinct movement sequences: 1 (bell, trumpet, whistle), 2 (trumpet, bell, whistle), and 3 (trumpet, whistle, bell). Each movement sequence is equivalent in total distance travelled based on equidistance between targets.

Participants reproduced the three step movement sequences in response to each of four different conditions, each with its own mode of presentation.

Condition 1 was visual instruction with the targets illuminated one at a time displaying the movement pattern to be performed. Condition 2 was verbal instruction with a recorded audio file of the experimenter's voice saying the movement pattern to be performed. Condition 3 was meaningful auditory instruction with recorded audio files of sounds corresponding to the instruments played one at a time signifying the movement pattern to be performed. Condition 4 was non-meaningful auditory instruction with audio files of high, medium and low tones (explained as representing top, middle, and bottom, respectively) played one at a time to signify the movement pattern to be performed. All audio files were professionally recorded at a recording studio and digitally engineered to control stimulus intensity and duration. Order of presentation was counterbalanced within each block of trials to offset any advantage or disadvantage that might occur from initial exposure to one of the four conditions.

Procedure

In order to familiarize the participants with the required procedure, the researcher demonstrated the protocol to each participant and had each complete 3 practice trials in each of the 4 conditions prior to the onset of experimental trials. Acquisition data consisted of 48 trials broken into two blocks with each block consisting of 6 trials (2 for each possible movement sequence) across the 4 conditions. The presentation of movement patterns within each condition as well as the order of presentation of the conditions within each block was counterbalanced across participants to rule out order of presentation effects that could possibly influence the results. Retention trials consisted of a single block of

24 trials and were performed one hour following completion of the acquisition trials. This final block of trials consisted of 6 trials for each of the four conditions. Descriptive, summary feedback was provided following completion of each condition (6 trials) during acquisition trials but not following retention trials. The total number of experimental trials was 72.

Each trial began with movement pattern instruction in one of the 4 conditions, followed by a start signal. The start signal varied depending on condition. Accordingly, the visual start signal was the fill colour of the home position switching from red to green, verbal was an audio file of the experimenter's voice saying 'go', meaningful auditory was an audio file of the sound of a clap, and non-meaningful auditory was a tone distinct in pitch and quality from those in the required sequence. A variable fore period of 0.5, 1.0, 1.5, or 2.0 seconds was placed prior to the start signal so that participants could not anticipate the onset of a trial. Average time of testing was 2 hours for comparison participants and 2.5 hours for participants with DS.

Data Collection and Analysis

All trials were run and recorded with E-Prime 2.0 which captured all movement data. The dependent measures recorded were reaction time (RT), movement time (MT), standard deviation of movement time (sdMT), total time (TT), and errors. For the purposes of this study, RT is defined as the time interval from the onset of the start signal to the initiation of a response and was measured from the beginning of the start signal to the release of the depressed mouse button. Depressing the mouse button signalled the participant's readiness to begin each trial. Movement time is defined as the time from the initiation of a response to sequence completion and TT as the time from stimulus onset to task completion (the sum of RT and MT). Errors are defined as any movement order other than the required sequence or a missing element from the required sequence. Only 1 error was noted per trial. Operationally, MT, TT, and errors were all measured, in whole or in part, by mouse clicks when the cursor is within each target. The independent variables were instruction type (visual, verbal, meaningful auditory, and non-meaningful auditory), group (DS, MA, CA), and block (acquisition 1, acquisition 2, retention).

Data analysis for RT, MT, sdMT, and TT was performed using a 3 group (DS, MA, CA) x 3 block (acquisition 1, acquisition 2, retention) x 4 condition (visual, verbal, meaningful auditory, non-meaningful auditory) mixed analysis of variance (ANOVA) with repeated measures on the last 2 factors. Post hoc analysis of main effects and interactions was conducted using Tukey's HSD with alpha level set at $p < .05$ for all analyses. Corresponding effect sizes are also reported for all statistical tests. All statistical analyses were performed using SPSS version 15.0 or STATISTICA version 8.

Data analysis for errors was performed by converting the raw error scores into percentages to obtain an error rate. The conversion of the raw scores into an error rate was necessitated by the ordinal nature of the original data and allowed for statistical comparison (Hays, 1994). Error rates were then analyzed using the same procedures as the other dependent variables described above.

IV. Results

The following analyses on reaction time, movement time, standard deviation of movement time, and total time were performed exclusively on error free trials. Due to limitations within the E-prime software, the timer would only stop when the following sequence was performed in order: the release of the mouse button followed by 3 accurate mouse clicks on the targets. If one of these steps were missed, the timer continued to run until the missing part of the sequence was completed. Thus, the timer successfully recorded the time required to complete a trial in which all 3 targets were clicked, regardless of whether or not they were correct, but continued to count if a target was missed or the mouse button was released prematurely. Therefore, errors of omission, in which part of the sequence was missing, could not accurately be recorded but errors of commission could. Unfortunately, there was no way to accurately determine which type of error occurred on all trials, only that an error had occurred. As such, all error trials were removed from further analysis.

Further, participants in both the DS and MA groups were highly variable in their performance of the required task resulting in outliers (defined as any point outside 2 standard deviations of the mean). While these outliers were expected, based on the relatively young developmental age of these participants, they needed to be corrected so as to not skew the distribution too far from normal. There were no outliers in the CA data. For the dependent variables (RT, MT, sdMT, and TT) all outliers were corrected to the mean plus or minus 2 standard deviations. Outliers were identified using the Kolmogorov-Smirnov Test for normality of distribution and Levene's Test of Equality of Error Variances for homogeneity of variance. Following the correction of outliers these tests were repeated to make sure that there were no remaining outliers that would affect the results. See Table 1 for a detailed breakdown of the number of outliers corrected across conditions.

Table 1. Number of corrected outliers as a function of dependent variable and condition.

Dependent Variable	Visual	Verbal	Meaningful Auditory	Non-meaningful Auditory
Reaction time	0	2	8	8
Movement time	1	1	0	4
Total time	1	3	8	9
Standard deviation of movement time	2	1	6	17

Reaction Time

Analysis of reaction time data produced a main effect for group, F (2, 18) = 11.263, $p < .001$, $\eta^2 = .556$, and for condition, F (3, 54) = 11.36, $p < .001$, $\eta^2 = .387$. These main effects were superseded by a 2 way interaction between group and condition, F (6, 54) = 4.095, $p = .0019$, $\eta^2 = .313$. Post hoc analysis revealed that for the DS group, RT was significantly slower in the visual condition (M = 596.29) when compared to both the verbal condition (M = 447.27, $p = .002$) and meaningful auditory condition (M = 469.07, $p = .015$) but was not significantly different than the non-meaningful auditory condition (M = 541.23, $p > .05$). For the MA group, however, the visual condition (M = 610.99) resulted in significantly slower RT from all 3 of the other conditions (verbal, M = 482.58, $p = .013$; meaningful auditory, M = 439.55, $p < .001$; and non-meaningful auditory, M = 484.66, $p = .016$). There were no significant differences between any of the 4 conditions for chronological age match participants. No other significant effects or interactions were found, see Figure 1.

Note: The Y error bars above the main data bar represents the standard deviation on all graphs and ***** depicts significant differences.

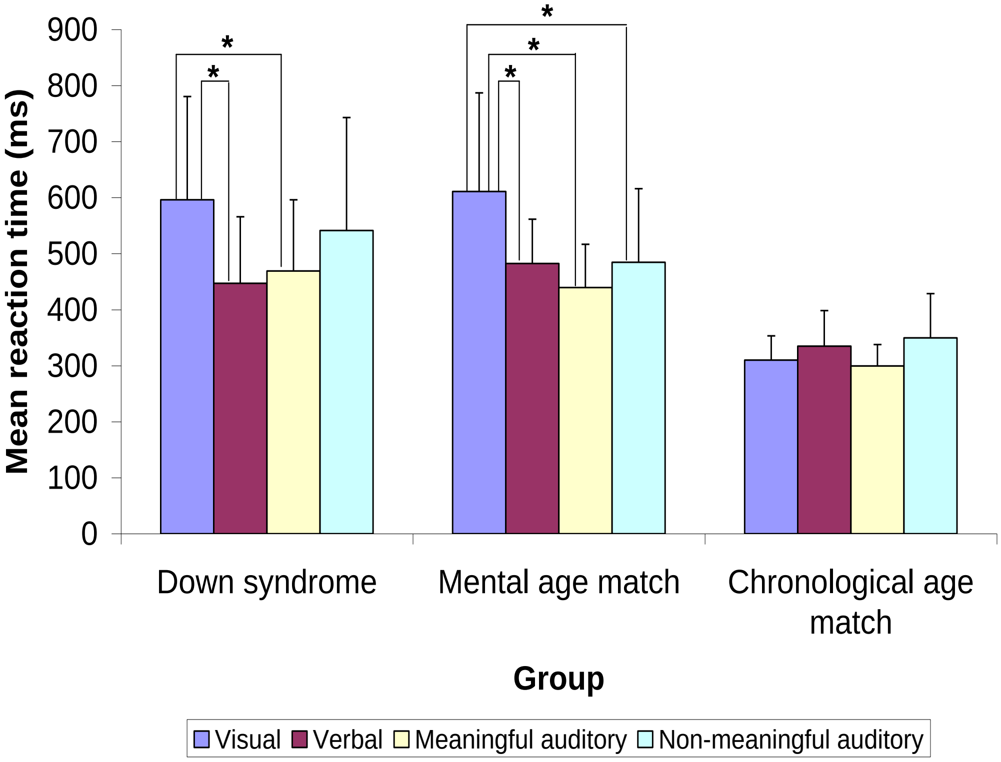

Figure 1. Mean reaction time for each group as a function of condition.

Movement Time

Analysis of movement time data revealed a main effect of group, *F* (2, 18) = 17.9, p < .001, η^2 = .665. Post hoc analysis indicated that the CA group (*M* = 1098.1) was significantly faster than both the DS (*M* = 2372.6, *p* < .001) and MA (*M* = 2420.6, *p* < .001) groups which were not different from each other, see Figure 2.

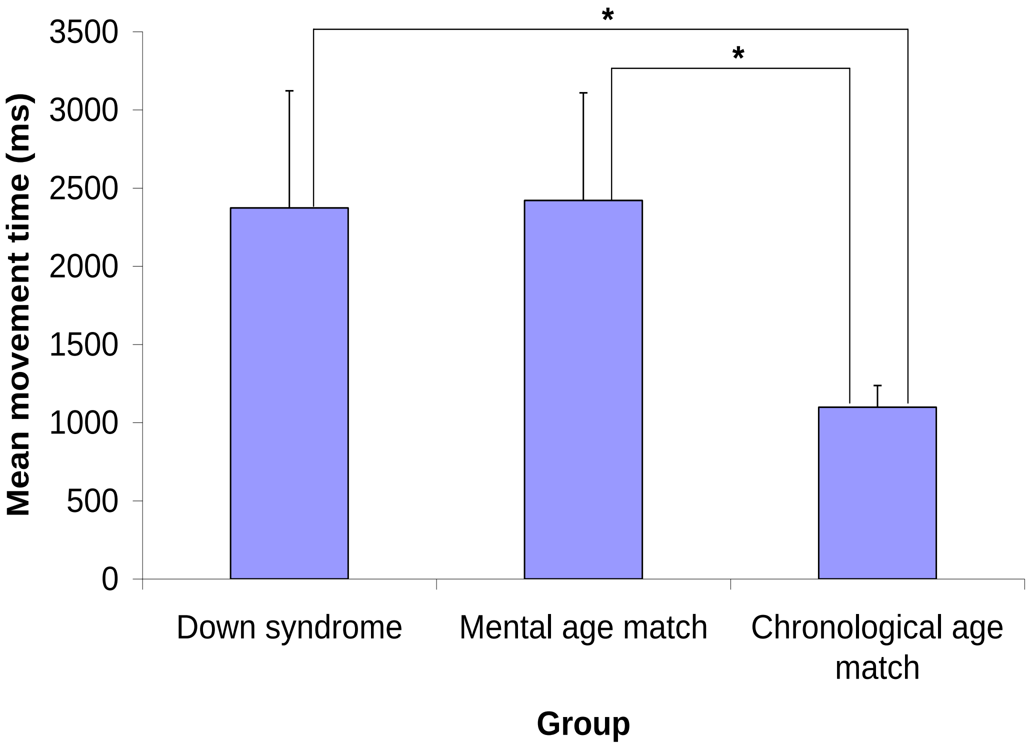

Figure 2. Mean movement time as a function of group.

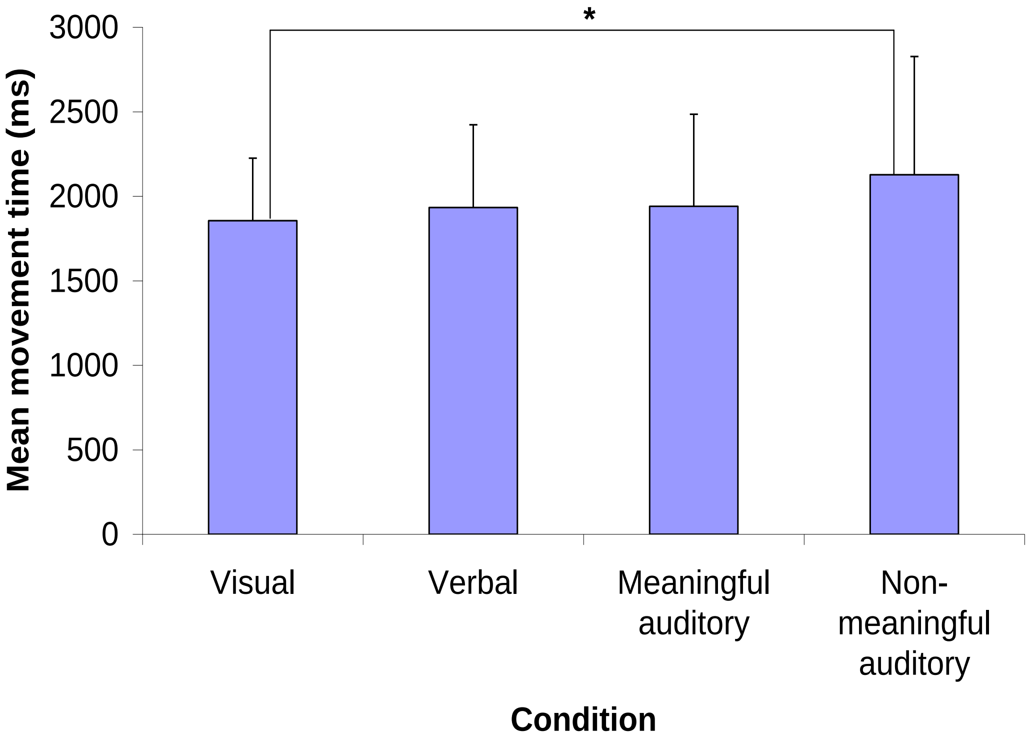

Figure 3. Mean movement time as a function of condition.

There was also a main effect of condition, *F* (3, 54) = 3.878, $p = .014$, $\eta^2 = .177$. Post hoc analysis indicated that the visual condition (*M* = 1855.2) was significantly faster than the non-meaningful auditory condition (*M* = 2127.0, $p < .001$). There were no other significant effects or trends, see Figure 3.

Standard Deviation of Movement Time

For standard deviation of movement time, analysis of variance revealed a main effect of group, *F* (2, 18) = 22.715, $p < .001$, $\eta^2 = .716$, see Figure 4. Post hoc analysis showed that the CA group (*M* = 105.04) was significantly less variable than the DS group (*M* = 372.84, $p = .001$) and the MA group (*M* = 522.44, $p < .001$). In addition, there was a trend towards the DS group being less variable than the MA group, but this difference did not quite reach traditional levels of significance ($p = .07$).

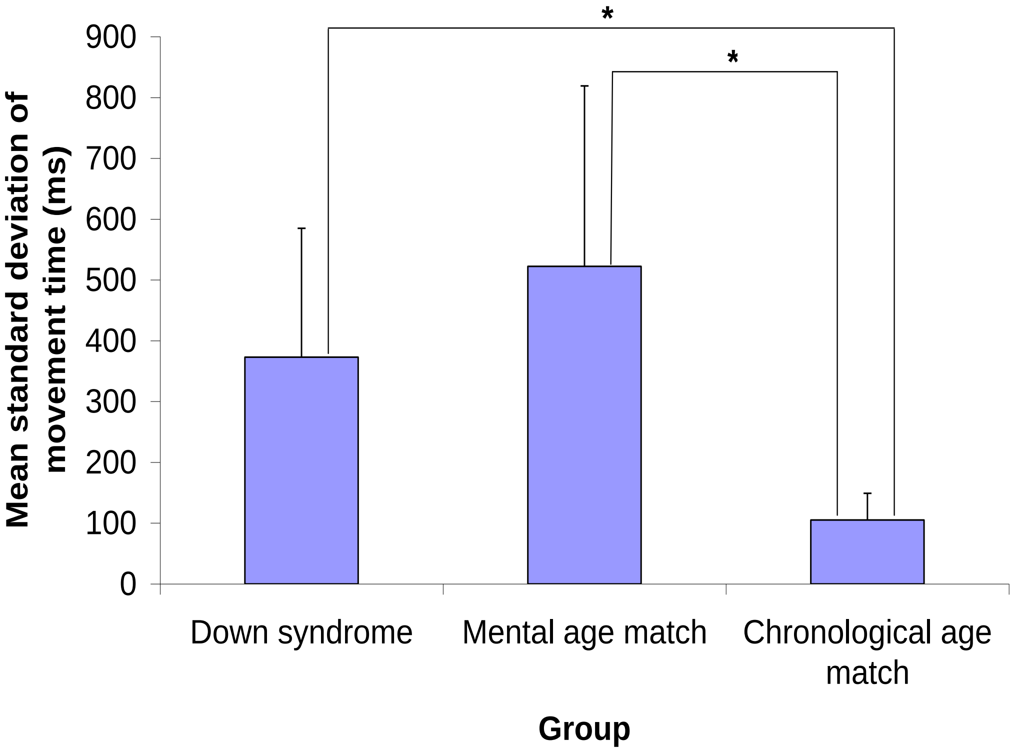

Figure 4. Mean standard deviation of movement time as a function of group.

Analysis also indicated a main effect of condition, *F* (3, 54) = 3.358, *p* = .025, η^2 = .157. Post hoc analysis revealed that the visual condition (*M* = 276.22) was significantly less variable than the verbal condition (*M* = 358.5, *p* = .0379) but just missed differing significantly from the non-meaningful auditory condition (*M* = 353.98, *p* = .0548), see Figure 5.

Both the main effect for block, *F* (2, 36) = 2.887, *p* = .069, η^2 = .138, and group x condition interaction, *F* (6, 54) = 1.9144, *p* = .095, η^2 = .175, approached traditional levels of significance but did not meet the criteria. No other effects or trends were found.

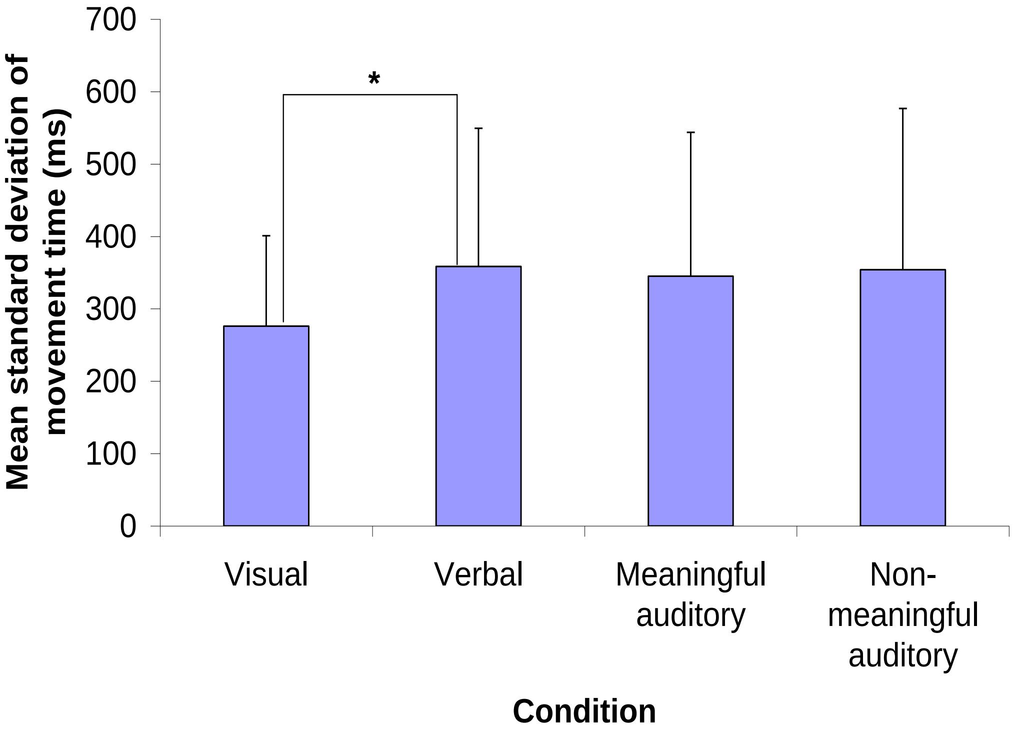

Figure 5. Mean standard deviation of movement time as a function of condition.

Total Time

Analysis of total time data revealed a main effect for group, *F* (2, 18) = 22.735, $p < .001$, $\eta^2 = .716$, with post hoc analysis indicating that the CA group (*M* = 1420.9) was significantly faster than both the DS (*M* = 2890.5, $p < .001$) and MA (*M* = 2925.1, $p < .001$) groups, see Figure 6. Further, there was also a main effect for condition, *F* (3, 54) = 4.226, $p = .009$, $\eta^2 = .19$, with post hoc analysis revealing that the non-meaningful auditory condition (*M* = 2591.6) was significantly slower than the visual condition (*M* = 2361.0, $p = .035$), verbal condition (*M* = 2354.8, $p = .029$), and meaningful auditory condition (*M* = 2341.3, $p = .019$), see Figure 7. Again, no other effects or trends were found.

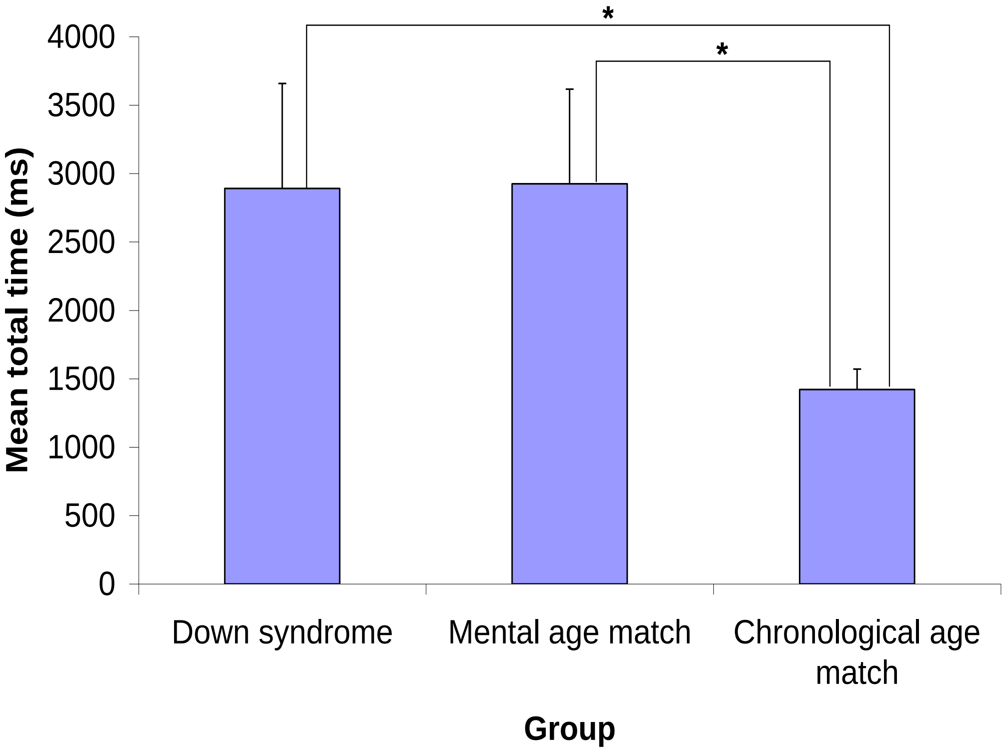

Figure 6. Mean total time as a function of group.

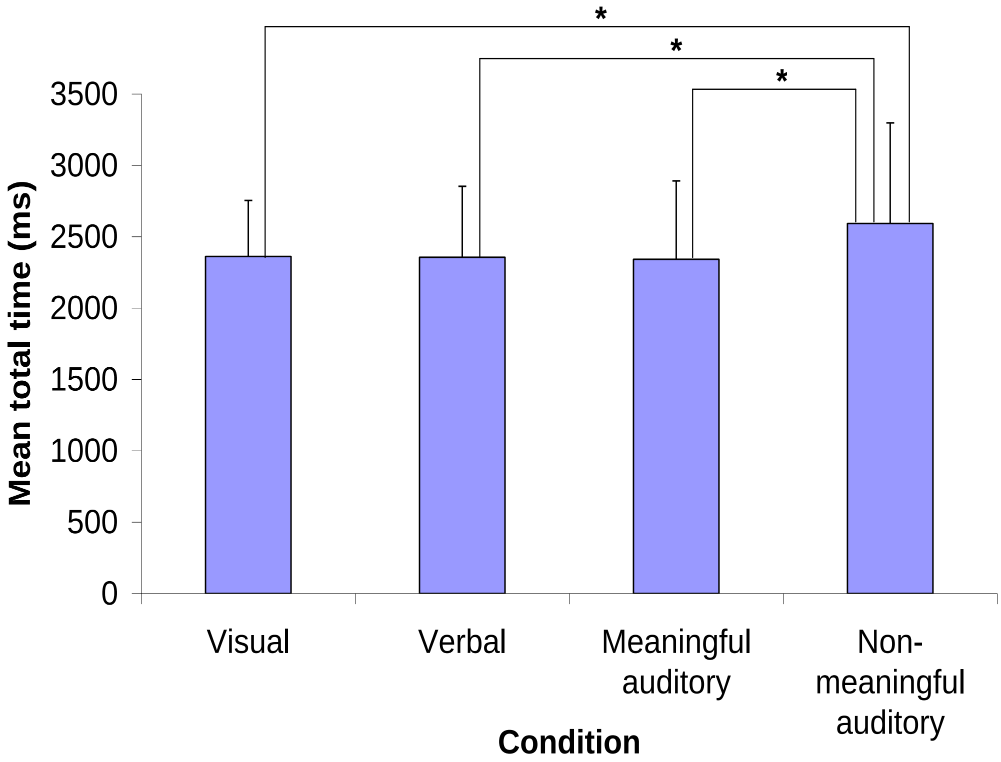

Figure 7. Mean total time as a function of condition.

Errors

Error results were analyzed by taking the number of errors committed and dividing them by the number of trials and multiplying that number by 100 to create an error rate expressed as a percentage. Mean error rates were then analyzed in the same manner as the other dependent variables previously described.

Analysis of error rate data produced a main effect for group, F (2, 18) = 13.499, $p < .001$, $\eta^2 = .6$, with post hoc analysis indicating that the CA group (M = 6.7) made significantly fewer errors than both MA (M = 25.6) and the DS (M = 34.5) groups (p < .001) who did not differ from each other. There was also a main effect for condition, F (3, 54) = 15.71, $p < .001$, $\eta^2 = .466$, with post hoc analysis indicating that participants committed significantly more errors in the non-meaningful condition (M = 38.1) than in the visual (M = 14.3), verbal (M = 18), and meaningful auditory (M = 18.8) conditions ($p < .001$).

These main effects were superseded by a 2 way interaction between group and condition, F (6, 54) = 4.543, $p < .001$, $\eta^2 = .335$. Post hoc analysis revealed that for the DS group, participants made significantly more errors in the non-meaningful condition (M = 19.8) than they did in the meaningful auditory (M = 31.7, $p = .01$), verbal (M = 28.6, $p = .003$), and visual (M = 19.8, $p < .001$). This pattern of committing significantly more errors in the non-meaningful auditory condition (M = 50.0) compared to meaningful auditory (M = 20.6, $p = .003$), verbal (M = 15.9, $p < .001$) and visual (M = 15.9, $p < .001$) was repeated exactly for the MA group. However, there were no significant differences between any condition (non-meaningful, *M* = 6.4; meaningful auditory, *M* = 4.0; verbal, *M* = 9.5; visual, *M* = 7.2) for the CA group (*p* > .05), see Figure 8.

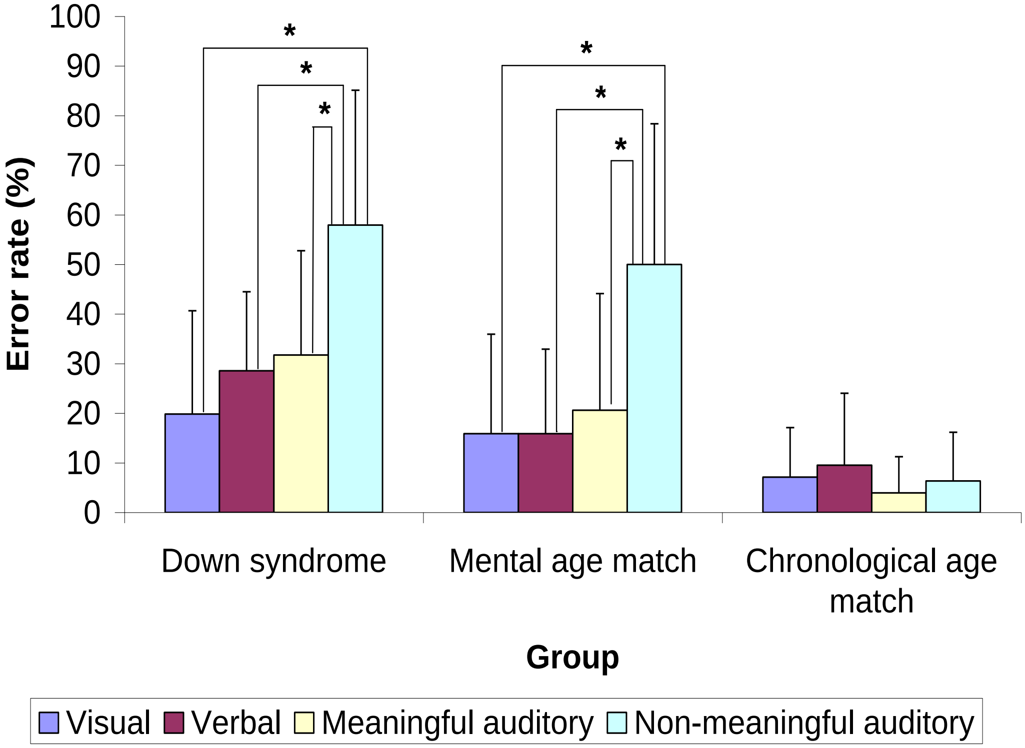

Figure 8. Mean error rate for each group as a function of condition.

V. Discussion

The purpose of the present study was to bridge the gap in the literature on perceptual motor behaviour in persons with DS by examining the effect of auditory information on motor performance and learning for persons with DS within the context of the model of biological dissociation first put forth by Elliott and colleagues in 1987. Recall that the model attempts to explain the visual-motor advantage and verbal-motor deficit for persons with DS through the syndrome specific pattern of cerebral organization unique to this population. The authors argue that despite an overall typical pattern of cerebral lateralization, the processing of language is atypically lateralized in the right hemisphere (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993). With respect to the present study then, it is believed that non-spatial/non-language visual information and movement production are both lateralized in the left hemisphere, language processing is lateralized in the right hemisphere, and non-verbal auditory information may be processed in either left or right hemisphere or both depending on the type of processing required. Given this syndrome specific pattern of cerebral organization it was postulated that participants with DS would perform best in the visual condition, followed by the meaningful and non-meaningful auditory, and then finally the verbal condition. Further, it was hypothesized that the differences between the conditions would be amplified following the retention interval based upon the few studies in which motor learning was assessed (Maraj et al., 2003). The results of the present study appear to at least partially support these hypotheses.

Looking first at RT, the results demonstrate a significant group x condition interaction in which participants with DS were significantly faster in their RT following verbal and meaningful auditory information than they were following visual information. Reaction time following non-meaningful auditory information was not significantly faster than following visual information but also not significantly slower than following verbal or meaningful auditory information. The same could not be said regarding their peers, with MA comparison participants' RT only varying following visual information in which they were significantly slower than they were following the other 3 types, and CA comparison participants displaying no significant differences across conditions. It appears, then, that there was a visual-motor disadvantage for both of the developmentally younger groups. While a visual-motor disadvantage in RT would be predicted for the TD MA participants based on the literature (Davis et al., 1991), it was not predicted for participants with DS.

The visual-motor disadvantage for participants with DS is contrary to both our hypotheses and the bulk of the literature on the model of biological dissociation but is not without precedent. In 2001, Welsh and Elliott also found that participants with DS displayed faster RT in response to verbal stimuli than in response to both direct and indirect visual stimuli; however, this pattern was reversed when it came to MT leading the authors to conclude that while verbal stimuli is sufficient in alerting persons with DS to initiate a response, it must still be transferred across the corpus callosum resulting in slower processing times and a temporal disadvantage relative to visual stimuli. While that argument may hold true in that instance, it does little to explain why the literature on perceptual motor behaviour in persons with DS consistently demonstrates faster RT in response to visual information or why in the present study MT is not faster in the visual condition compared to the verbal condition (a point we will return to later in this section).

A more reasonable explanation may be that both Welsh and Elliott (2001) and the present study appear to be in the minority when it comes to manipulating the type of stimulus used to signal the onset of a trial. Recall from the review of literature that many of the studies cited provided either visual or verbal instruction but then used an auditory tone to initiate the onset of each trial. Unfortunately, the Welsh and Elliott study is a discrete RT time study in which participants simply moved their hand from a home position to a target following a visual or verbal cue. There was no instruction prior to the trial as the visual or verbal cue to initiate the motor response acted simultaneously as both the type of instruction and movement imperative. The present study, being serial as opposed to discrete in nature, placed greater cognitive demands on the participants as they were required to watch or listen to instructions, process that information, respond to the trial onset stimuli, and then perform the movement. As previously discussed the complexity of the present task is much greater than that of the discrete RT study of Welsh and Elliott (2001) making comparison difficult. To the best of my knowledge this is the first study to match the mode of the start signal to the mode of instruction and as such the results may be unique to the field.

Yet another reason for the slower RT in the visual condition for persons with DS may be due to differences in signal strength. While the signal strength for the verbal, meaningful auditory, and non-meaningful auditory conditions were controlled through digital sound editing software, the visual stimulus being non-auditory in nature could not be controlled in this same manner and had to be approximated. As such there was no way to guarantee that the signal strength of the home position turning from red to green was of the same intensity, and therefore as alerting, as the audio files. Moreover, due to limitations within the E-prime software, all trials began with the home position turning red and this colour disappearing with the presentation of the start signal. Thus, each non-visual trial was signalled by both the disappearance of the colour red from the home position as well as the presentation of a sound, while each visual trial was signalled only by the home position changing from red to green. While the red colour in the home position was simply designed to direct the participants to the home position to begin each trial, its removal in combination with the onset of a sound may have served to amplify the intensity of the start signal in the non-visual trials resulting in faster RT similar to the sound and light condition in the Davis et al. study (1991).

Another contradictory result with respect to the literature is that participants with DS demonstrated slower RT following non-meaningful auditory information than they did following both meaningful auditory and verbal information but not visual information. Again, this result was not predicted but is not surprising considering that the non-meaningful auditory information was designed to be less meaningful than the other three conditions. Participants with DS were slower in reacting to non-meaningful auditory information as this condition was inherently vague and purposefully unfamiliar, resulting in greater cognitive demands and thus slower RT. This greater cognitive demand did not result in significantly slower RT for the MA group who were also developmentally young however.

One of the aims of the present study was to examine the effect of meaning on motor performance and learning and so the non-meaningful auditory stimuli were designed to be less meaningful than the visual, verbal, and meaningful auditory stimuli. Further, it was hypothesized that non-meaningful auditory information would result in increased processing time and resultant lower levels of performance than that of the meaningful auditory information. Tones of different pitches, namely high, medium, and low, do not inherently correspond to images at the top, middle, and bottom of the screen. In the present study all participants were instructed that the high tone corresponded to the top picture, the medium tone corresponded with the middle picture, and the low tone corresponded with the bottom picture. They were then given the opportunity to practice (recall that each participant completed 3 practice trials in each of the 4 conditions). So, while it was entirely possible that a participant would interpret, on their own, which tone represented which target, it was expressly indicated to each that there was in fact only one acceptable interpretation. The explanation of the meaning requires interpretation or, possibly, misinterpretation of the stimuli prior to completing the required task which increased the amount of time required to process the information resulting in slower RT. Based solely on cerebral lateralization we would expect that non-meaningful auditory information would result in faster RT compared to both meaningful auditory and verbal information due to left hemisphere lateralization of pitch and right hemisphere lateralization of timbre and speech. This pattern of results was not borne out in the present results however as both verbal and meaningful auditory RT were superior to non-meaningful auditory despite the fact that both are processed in the right hemisphere. This reversal of results from what would be predicted based on cerebral organization suggests that meaning has a profound impact on motor performance for persons with DS and may be a powerful predictor of future performance.

Further, it could be argued that the difference between meaningful and non-meaningful information lies not only in the inherent qualities of those stimuli but rather in their familiarity to the individual. Certainly our ability to understand language as well as to associate a musical note with the instrument it came from both require interpretation. However, based on the familiarity of the stimuli chosen the interpretation and integration of stimuli was done years prior and did not require interpretation at the time of testing. Imagine for example if the language used was German as opposed to English and the musical instruments were a sitar, glockenspiel, and oboe instead of a bell, horn, and whistle. Would the information be as meaningful? Likely not. In this new situation what was once familiar and therefore meaningful information has become unfamiliar and non-meaningful despite the fact that the modality of the information remains the same. This argument is supported by the present results which show similar levels of performance among the four conditions for the CA participants who exceed the participants with DS and their MA peers in both developmental level and experience.

It is worth noting that familiarity was a primary factor in the selection of all stimuli. Boardmaker™ pictures were used in the visual condition as they are commonly used in visual supports utilized by professionals such as educators, speech language pathologists, occupational therapists, and physiotherapists.

Words are the most commonly used form of communication and the three musical instruments are all very common in any music room or household as well as each being very distinct in the sound that they make. Lastly, high, medium, and low tones were chosen because while not as inherently meaningful as the others tones are often associated with changes in level (e.g., climbing stairs in cartoons).

Clearly the RT results were not as hypothesized but given the pioneering spirit of the present study they are also not outside of what could be expected. Two other temporal measures (MT and TT) were also measured and their results must be compared to those for RT. First, it is important to note that there were no interactions for either measure just main effects. As such, there are no differences in the patterns between groups, just differences in the levels of performance.

As with RT, CA participants were faster in both their MT and TT than either developmentally younger group which did not differ from each other. Further, for both dependent measures participants were slowest following non-meaningful auditory information. With respect to MT, however, only the visual condition differed significantly from the non-meaningful auditory condition. This difference demonstrates a visual-motor advantage for MT but only relative to non-meaningful auditory information. The visual-motor advantage was predicted but was expected to be present relative to all other conditions not simply relative to the one non-meaningful source of information. With respect to TT, non-meaningful auditory information resulted in significantly longer total response times compared to each of the three meaningful conditions. This demonstrates a clear division between meaningful and non-meaningful information regardless of the modality of presentation. Again these results support the argument that meaningful information leads to a processing advantage relative to non-meaningful information and that familiarity is closely linked to level of meaning (Ringenbach et al., 2006).

Despite the lack of a consistent temporal advantage for visual information there are two other dependent measures to examine. The first of these measures is variability. Results for standard deviation of movement time show a significant advantage in variability only for the CA participants relative to either developmentally younger group. Chronologically age matched participants were much more consistent in the length of time required to complete the required movement sequence across trials compared to either participants with DS or MA participants. This difference in consistency is reflective of the low cognitive demands for this group to complete the required task compared to the relatively high cognitive demands for their developmentally younger peers, especially in certain conditions. Essentially, the CA participants were not challenged by the task regardless of condition resulting in a sort of ceiling effect with little variability as well as a very low error rate (another point we will return to later in this section).

However, while the only statistically significant difference in variability was between CA participants and both developmentally younger groups, a closer look shows that there was also a trend for participants with DS to be less variable overall than their MA peers. This discrepancy in variability between participants with DS and MA participants approached conventional levels of significance (p =

.0695) and is likely the result of reduced power resulting from having only 7 participants in each group as opposed to the desired 10. Given the assumption of equivalent mental ages between the two groups it is tempting to speculate that the discrepancy in variability (if it were to be statistically significant) would be due simply to more experience resulting from the greater chronological age of the participants with DS. The greater the experience is with processing a particular type of information the more familiar it is, and thus more consistent the response (Schmidt & Wrisberg, 2000).

The results also indicate that participants were more consistent in their response to visual information than they were in their response to verbal information. While this pattern held across all participants, it is most noteworthy for participants with DS who uncharacteristically demonstrated a visual-motor disadvantage in RT when compared the verbal condition. This reversal in performance back to a visual-motor advantage and verbal-motor deficit for participants with DS is a return to the expected pattern of results predicted by the model of biological dissociation (Elliott, Weeks, et al., 1987; Elliott & Weeks, 1993) but also an explanation for the anomalous RT results. It appears that while they were indeed slower in their RT following visual than verbal information, they were more consistent in their completion of the movement sequence following the former suggesting a trade-off of speed for consistency.

Unfortunately, only two other studies cited in this paper reported standard deviation of movement time as a dependent variable. The first study by Davis et al. (1991) demonstrated that typically developing CA participants were more consistent than both participants with DS and their peers with UnDD. Moreover, there were no differences for participants across light, sound, and light and sound conditions. The second study by Robertson and colleagues (2002) found that adults with DS displayed a standard deviation of movement time that was, “roughly twice as high as that observed for children and three times higher than that observed for the adults without DS” (p. 218). Further, participants with DS were most variable in the visual condition while their MA peers were most variable in the verbal condition. The results from the present study are not consistent with the results of either study in two important ways. First, there was a trend for participants with DS to be more consistent overall when compared to their MA peers. Second, participants in both developmentally younger groups were more consistent in their movement time with visual information as opposed to verbal information.

The second non-temporal dependent measure is errors. The results of the present study indicate that participants with DS made the most errors, followed by the MA participants, and then CA participants who made the fewest. Not only did the two developmentally younger groups commit more errors overall, but their pattern of errors was similar as well. Both participants with DS as well as their MA peers made significantly more errors in the non-meaningful auditory condition compared to the 3 meaningful conditions. Error rates for CA participants were similar across all conditions.

What is clear from the error rates is that the required task was quite difficult for both developmentally younger groups. This is evidenced from the high overall error rates (participants with DS committed errors in roughly one third and their MA peers in roughly one quarter of all trials) as well as the fact that both groups committed significantly more errors in the non-meaningful auditory condition which was designed specifically to be less meaningful than the other 3 conditions and thus more difficult. This clear performance difference between meaningful and non-meaningful was also demonstrated in TT suggesting that increased cognitive demands results in both a speed and accuracy deficit. The high error rates associated with the present task are not without precedent though as a 2003 study by Welsh, Elliott, and Simon support this pattern of error results. Specifically, they found that the number of errors increased with task difficulty and that in the most difficult condition participants with DS performed at a level that was not better than chance.

Beyond the relationship between cognitive demands and error rate, the present pattern of error results is unique in the literature in two important ways. The first is that the vast majority of studies in which errors were reported were variations of dichotic learning tasks in which differing information was presented simultaneously to the left and right ear. Consequently, the errors reported were side to side errors in response solely to verbal information (Hartley, 1981; Heath et al., 2005; Weeks et al., 1995; Welsh et al., 2003). Only a single study reported errors in response to both visual and verbal information (Elliott et al., 1990). The second is that of the few studies that directly compared motor performance for persons with DS in response to visual, verbal, and non-verbal auditory information, none examined errors (Davis et al., 1991; Ringenbach et al., 2002;

Ringenbach et al., 2006; Robertson et al., 2002). As such the results of the present study are without precedent.

Another important point with regard to errors is that participants can vary in the types of errors made as well as they amount. While it did not examine non-verbal auditory information, Elliott et al. (1991) introduces a very important point for the present discussion; namely that the overwhelming majority of errors made by all participants were the result of completing the sequence out of order. The remainder of the errors were the result of anticipation, in which the participants began their movement prior to start signal, or the movement being performed with the wrong hand (Elliott et al., 1991). The present study found not only sequencing errors and anticipation errors but also errors in which a target or targets were missed. Further, the types of errors committed varied across group and condition. Experimenter notes taken during each testing session indicate that for CA participants only 2 errors were due to performing a sequence other than that required, all other errors were due to missing a target in the sequence (due to over or undershooting it) or anticipation errors in which the mouse button was released prematurely. The same cannot be said for the two developmentally younger groups of participants as they made multiple errors of each type.

There was, however, one important difference between these two groups in that more participants with DS completed sequences that were not one of the three possible movement sequences than did their MA peers. While it was never explicitly mentioned to any of the participants that there were only three possible movement sequences, it became implicit to many of them that this was in fact the case. As such for CA participants and the vast majority of the MA participants, when they did perform a movement sequence other than the one required, it was one of the three possible movement sequences which they had performed numerous times during practice trials and previous experimental trials. For participants with DS and only a couple of MA participants, sequencing errors were committed in which they completed a movement sequence that was not even a possibility (e.g. whistle, trumpet, bell). Further, there were more implicit/not possible sequencing errors in the non-meaningful auditory condition in which the participants were the least successful overall.

Implicit knowledge is one indicator of motor learning (Schmidt & Wrisberg, 2000). Observations of participants with DS completing movement sequences other than one of the three possible, demonstrates the difficulty they had both performing and learning the task relative to their peers. The differences in motor performance have been discussed at length thus far; however, differences in motor learning have not. The failure of participants with DS to implicitly understand that there were only three possible movement sequences despite repeated practice indicates that their performance did not improve over time.

As previously discussed motor learning is not directly observable; it is inferred from multiple observations of motor performance (Schmidt & Wrisberg, 2000). Learning is presumed to have occurred when there are performance improvements in accuracy, efficiency, and time (Guthrie, 1952; Schmidt & Wrisberg, 2000). While analysis of efficiency is beyond the scope of the present study, both accuracy and time results do not support the second hypothesis that

that performance differences between the conditions would be amplified following the retention interval resulting in a greater learning effect compared to performance effect.

While the discussion up to this point has focused on performance differences both between groups and between conditions there were no significant main effects for block for any of the five dependent variables indicating that these differences did not changed over time. There was, however, one main effect that did approach traditional levels of significance (p. = .0687) but did not meet the criteria. Accordingly there was a trend for participants to be the most variable in their MT in the first block of acquisition trials, least variable in the second block of acquisitions trials, with variability in the retention trials intermediate the two.

The lack of learning effect in the present study is both unexpected and contrary to the previous results (Maraj et al., 2003; Meegan at al., 2006) which demonstrated performance improvement over time. While it is possible that visual, verbal, and auditory instruction does not affect motor learning, it is unlikely given previous results. Given the history of significant learning effects, there are two likely explanations for the lack of significance in the present study.

The first is that the study lacked the power to detect the difference (Type II error) due to insufficient numbers of participants (Hays, 1994). This explanation has some credence as the number of participants in each group was reduced from 10 to 7 due to a lack of suitable volunteers with DS. The reduction in power that resulted from lower than anticipated number of participants is particularly relevant with respect to the previously mentioned non-significant main effect for block for sdMT. Recall that this main effect narrowly missed the cut off for significance and may have reached that mark had there been more participants.

The second explanation is that there may have not been an adequate number of trials to facilitate learning or that the amount of time between acquisition and retention trials was insufficient. As previously discussed, many participants with DS and a couple of MA participants did not implicitly understand that there were only three possible movement sequences and performed sequences that were not even possibilities on some error trials. This suggests that individuals who are developmentally younger are unable to encode the response criteria as well as their developmentally older peers and may require increased repetition in order to facilitate similar levels of implicit learning. Further, this difficulty encoding may be offset by increasing the amount of time available to the learner as well as the amount of exposure. The present study incorporated a single retention interval which followed the completion of acquisition trials by 1 hour. One hour may not provide sufficient time for participants to integrate the pertinent information required for the task such that there is a significant increase in performance. Recall that Maraj et al. (2003) found a relatively small but significant learning effect following the 1 hour retention interval but that this effect was amplified following a subsequent 24 hour interval suggesting that the amount of time allowed for encoding is indeed important for facilitating learning.

VI. Conclusion

Summary and Conclusion

As expected the results of the present study confirm the visual-motor advantage for persons with DS that is consistently demonstrated in the literature (Maraj et al., 2007). Not expected, however, was that the visual-motor advantage was not found in RT but rather only in MT and sdMT. So while they were not faster in responding to visual information, they were faster once a response was initiated and more consistent in that response. When looked in its entirety, it appears that in the visual condition participants with DS adopted a strategy in which they traded speed for consistency in order to complete the required task. This strategy appears to be unique within the literature and somewhat paradoxical. As previously discussed, left hemisphere lateralization of both visual processing and movement production should result in both a temporal and consistency/accuracy advantage due to the close proximity of the cerebral centres responsible for visual processing and movement production and their subsequent ease of communication. The unexpected temporal disadvantage for RT in the visual condition cannot be explained by the above rationale and suggests that the relationship is perhaps not as straightforward as previously thought.

The lack of linearity between the proximity of processing centres and outcomes is further highlighted by the overall demarcation between motor performances following non-meaningful information compared to those following meaningful information. Across most dependent variables participants with DS performed markedly worse in the non-meaningful auditory condition compared to the visual, verbal, and meaningful auditory conditions. The obvious distinction between the two is that the former was designed to be inherently non-meaningful while the latter were designed to be meaningful. The clear difference in performance between the meaningful conditions and non-meaningful condition, in combination with further differences between the 3 meaningful conditions, highlights the complex nature of the interactions between variables.

Not only was there a clear difference in performance between the meaningful conditions and the non-meaningful condition, but this difference seemed to be consistent regardless of the type of processing that occurred. By far the most consistent finding in the present study was the poor performance of participants with DS in the non-meaningful auditory condition across most dependent variables. Theoretically tones of different pitches should be processed in the left hemisphere along with movement production resulting in an advantage relative to meaningful auditory and verbal information which should both be processed in the right hemisphere. This, however, was not the case and for the most part non-meaningful auditory information resulted in a significant deficit relative not only to visual information but also to meaningful auditory and verbal information. The most obvious explanation for this contradictory result is that the non-meaningful auditory condition was simply too hard for the participants with DS. This explanation is supported by the high error rates overall for both developmentally younger groups of participants that indicate the high cognitive demands to successfully complete the required task. These error rates soar even higher in the non-meaningful auditory condition such that both groups were unsuccessful at least half the time. It also appears that not only is meaning closely related to performance but so to is familiarity as not only was the non-meaningful auditory information the least meaningful but also the least familiar further contributing to the observed deficit in this condition.

Unfortunately, while the present study at least partially supports the visual-motor performance advantage found in previous studies it fails to support the associated learning advantage. It is unclear as to why the performance of participants did not improve over time but a trend towards increased consistency for MT suggests that this discrepancy may be due to methodological reasons. Some of which are the addressed in the following section.

Future Direction and Recommendations

Overall, the results of present study support the model of biological dissociation upon which it was predicated. It was an initial attempt to bridge the conceptual gap in the literature by examining the effect of auditory instruction in comparison to the fundamentals of visual and verbal instruction. The gap, however, was substantial and other studies are needed in order to provide the continuity needed to form a strong argument. It is for this reason the following recommendations are made to help guide future research.

More studies directly comparing visual, verbal, and auditory instruction are required. These studies should cover the full range of motor tasks that can be performed and should include discrete, sequential, and continuous tasks. Further, these studies should focus on motor learning as well as performance, as motor learning has largely been absent in the literature. Specifically, performance should be evaluated following longer retention intervals such as 24 hours, 48 hours, and/or 1 week following acquisition trials. Increased stability of performance across time is fundamentally important in increasing the quality of life for persons with DS and this area has, for the most part, been ignored to date.

Further to this point, future studies should examine the efficiency with which movements are made as opposed to just the amount of time required to complete the movement or number of errors committed. Efficiency is the third characteristic of skilled performance mentioned previously (Guthrie, 1952; Schmidt & Wrisberg, 2000) but is rarely studied as it often more difficult to define and quantify. In the present study, experimenter notes during testing suggest that participants with DS were less efficient in their movements than their peers, moving the mouse in more rounded pattern between targets as opposed to a straight line. This pattern suggests that participants with DS may still be processing the movement instructions during their execution of the motor tasks, but this interpretation is purely speculative without the means to objectively examine the quality of the movement being performed. Kinematic analysis of the movements in combination with temporal and error data would provide the most thorough description of motor skill acquisition.

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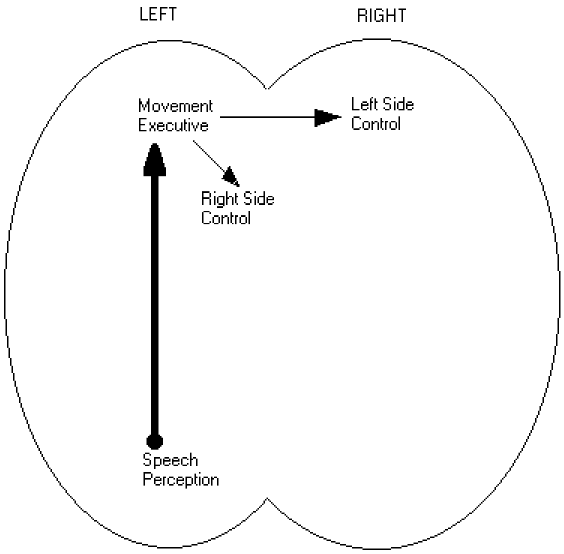
Appendix A

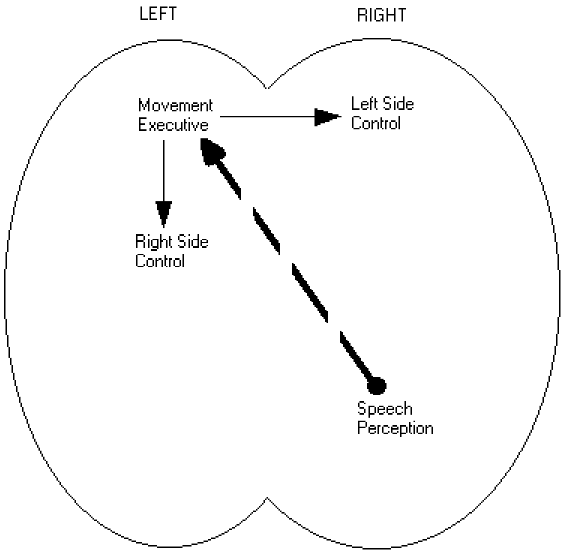
Figure A1. Model of cerebral organization in individuals with Down syndrome.

Note. Adapted from Elliott, D., & Weeks, D.J. (1993). A functional systems approach to movement pathology. Adapted Physical Activity Quarterly, 10, p.317.

General Model



Down Syndrome Model



Appendix B

Hearing Screening Procedure

1. Select a quiet location (e.g., a carpeted room removed from the main traffic flow of the school).

2. Ask if experimenter has any functional hearing impairments.

(Steps 1 and 2 are already complete.)

3. Sit experimenter in a chair facing door from tester at side of table. Arrange experimenter, tester and equipment so that tester can observe the experimenter's non-verbal response to sound but the experimenter cannot see the tester's hand on the stimulus button.

4. Turn power on (center button is down) and ensure pulse is off (right button is up).

> "Today we are going to play a fun game called the listening game. Do you know what these are called [show the headphones]? ...That's right. What do you use headphones for? ...Good. And what do you hear when you listen to headphones? ...That's right- sometimes you can hear music. But today I am going to let you listen to my headphones and you won't hear music. Instead you can hear a little beep. I am going to put the headphones on you now so you can listen for the little beep."

5. Put headphones on experimenter **(red over right ear; blue over left ear)**, taking care to align each headphones 'output circle' with the experimenter's ear canal opening.

> "Now listen for the beep [present a 1000 Hz tone at 65 dB HL] – can you hear that? ...Good. So when you hear the little beep I want you to drop a marble into the other side container [show the container and drop a marble in it] – Ok? Sometimes it is going to sound like a whistle [present a 2000 Hz tone at 65 dB HL] – can you hear that one? ...Good – so you drop another marble into other side [drop a marble into the container] – but only when you hear a sound. Sometimes it is going to be low like a fog horn [present a 500 Hz tone at 65 dB HL] – can you hear that one? ...Good – and so you drop another marble into the container [drop a marble into the container] – but only when you hear a sound! And the sounds are going to be softer and softer. Sometimes you can't hear anything. Can you hear one now [no sound]? ...It's gone! So if you can't hear anything, don't drop the marble yet but listen very carefully [listen carefully] until you hear [present a 1000 Hz tone at 65 dB HL] another little sound – then you can drop the marble again [drop a marble into the container] – Ok? So only when you hear a sound... and they are going to get softer and softer. Now we are going to play the game.

6. Complete hearing screening as follows:

RIGHT EAR

For each tone:

Ensure right ear is on (left button is down).
Adjust right knob to given frequency.
Adjust left knob to given decibel level.
Push and hold stimulus button for 2 seconds

1000 Hz 2 second sound at 40 dB (orientation tone)
1000 Hz 2 second sound at 30 dB (altering tone)
1000 Hz 2 second sound at 20 dB (test tone) **"Record on data sheet"**
2000 Hz 2 second sound at 30 dB (alerting tone)
2000 Hz 2 second sound at 20 dB (test tone) **"Record on data sheet"**
4000 Hz 2 second sound at 35 dB (alerting tone)
4000 Hz 2 second sound at 25 dB (test tone) **"Record on data sheet"**
500 Hz 2 second sound at 35 dB (alerting tone)
500 Hz 2 second sound at 25 dB (test tone) **"Record on data sheet"**

LEFT EAR

For each tone:

Ensure left ear is on (left button is up).
Adjust right knob to given frequency.
Adjust left knob to given decibel level.
Push and hold stimulus button for 2 seconds

1000 Hz 2 second sound at 30 dB (alerting tone)
1000 Hz 2 second sound at 20 dB (test tone) **"Record on data sheet"**
2000 Hz 2 second sound at 30 dB (alerting tone)
2000 Hz 2 second sound at 20 dB (test tone) **"Record on data sheet"**
4000 Hz 2 second sound at 35 dB (alerting tone)
4000 Hz 2 second sound at 25 dB (test tone) **"Record on data sheet"**
500 Hz 2 second sound at 35 dB (alerting tone)
500 Hz 2 second sound at 25 dB (test tone) **"Record on data sheet"**

7. Take headphones off and turn off power (center button is up).

Pass = Participant responds to all test tones in both ears
Fail = Participant does not respond to one or more test tones in either ear

If participant fails, try retesting same day (two same day failures -> audiologist referral)

Appendix C

Figure C1. Visual representation of computer screen during experimental protocols in visual condition.

Appendix D

Table D1. Descriptive statistics for group equivalencies among participants.

Group	Chronological age	Mental age
Down syndrome	22.93	7.89
Mental age match		7.19
Chronological age match	22.95	

Appendix E

Participant Information Letter

The effect of auditory instruction on upper limb motor performance and learning for persons with Down syndrome.

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Phone: 780-492-8649
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E-mail: brian.maraj@ualberta.ca

Dear Participant,

I am a student at the University of Alberta. I would like to invite you to help me in a study. I am interested in how different kinds of instructions help people to learn a movement pattern. Different kinds of information are processed in different parts of the brain. Some parts of the brain are better for learning than others. I am trying to find the best way to teach people. I want to find out if it is better to show you what to do, to tell you what to do, or use music or sounds to teach you. The data I collect from you will be used in my graduate thesis.

We will be working on a computer. The screen will have pictures of a bell, a trumpet, a whistle, and a circle on it. You will need to use a mouse to click on these pictures in order. I will use four different ways to teach you the order. I will **show** you by making the pictures light up. I will **tell** you by saying the names of the pictures. I will play **music** from the instruments. I will play **sounds** than sound like beeps. The order I teach you will change each time but I will only teach you one way at a time. After I teach you the movement pattern I will ask you to move the mouse from the circle to the shapes as fast as you can. Try not to make mistakes. A clock in the computer will show you how fast you were and if you got them all right. You will do this several times and then we will take a break. After our break, I will teach you the order again. You will have less movement patterns to do this time. I will only need your help for 2 hours and then you can go home.

There is no reward for participating in this study but your results will help me to understand how you learn movements. The results of this study will help me learn the best way to teach people with Down syndrome, and others, in the future. There is no risk to you for participating in this study.

You can stop participating in the study at any time. Just tell me or tell your parents/guardian that you want to stop. If you stop and do not want to finish, all of your information will be removed from the study if you ask.

Your information will be kept confidential. Your name will not be used and raw data will be coded and kept in a locked office. Only the investigators have access to this data. Normally data is kept for five years after it is published. After that it will be destroyed.

If you have any questions about what I am doing, you may call me at 780-492-0578. If you have any concerns about this study, you may contact Dr. Wendy Rodgers, Chair of the Faculty Research Ethics Board, at 780-492-8126. Dr. Rodgers has no direct involvement with this project.

Thank you.

Cameron Bonertz
Graduate Student

Appendix F

Participant Information Letter (Parents/Guardians)

The effect of auditory instruction on upper limb motor performance and learning for persons with Down syndrome.

Principal Investigator: Cameron Bonertz,
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Co-Investigator: Dr. Brian Maraj,
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Phone: 780-492-8649
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E-mail: brian.maraj@ualberta.ca

Dear Parent/Guardian:

I am a graduate student at the University of Alberta. I would like to invite your child or ward to participate in a study. The purpose of this study is to examine how different types of instructions help people learn movement patterns. Different types of information are processed in different parts of the brain and I am interested in which parts of the brain help facilitate learning. I want to find out whether it is better to show them what to do, tell them what to do, or use music or sounds to teach them what to do. I also want to find out whether information that is more meaningful further aids in learning. The data collected from your child or ward's participation will be used in my graduate thesis.

Participants will use a mouse to move a cursor on a computer screen directly in front of them. They will use their right hand to move the cursor from the home position at the bottom of the screen to shapes of musical instruments in a specific order. I will teach them the patterns in 4 different ways. I will show them the sequence by having the instruments light up. I will tell them the sequence by saying the names of the instruments. I will play music from of each musical instrument and I will play sounds that will sound like beeps so that they hear the order. After they learn the sequence, I will ask them to move the cursor from the home position to the musical instruments as fast as they can without making mistakes. The computer will display how fast they were able to complete the sequence and if they were correct. They will complete 48 trials and it will take approximately 15 minutes. Following the 48 trials, we will take a 1-hour break in which we will go to the Student's Union Building for a snack. After the break, they will complete another 24 trials. Total time for testing is expected to be less than 2 hours.

You may remain in the laboratory during testing or you may leave. Your child or ward is free to withdraw from the study at any time without consequence by simply informing me either verbally or in writing. If you choose leave, we require a contact number at which we can reach you should your child or ward withdraw. Upon withdrawal from the study, their information will be removed from the study upon request.

There are no rewards for participation. However, your child or ward will benefit by having an audiology and vision assessment. Further, the results of this study will help us understand how persons with Down syndrome learn motor skills. There are no known risks associated with this study.

Your child or ward's name will not be used. All personal information will be coded and stored in a locked lab. Only I will have access to this information. I will review your child or ward's results for this study, but their names will not be used. Normally data is retained for a period of five years post publication, after which it will be destroyed.

Following the completion of the study, a presentation of the findings will be made to the Edmonton Down Syndrome Society. Interested participants and their families are invited to come and learn more about the project and its final outcome.

If you have any questions about what I am doing, you may call me at 780-492-0578. If you have any concerns about this study, you may contact Dr. Wendy Rodgers, Chair of the Faculty Research Ethics Board, at 780-492-8126. Dr. Rodgers has no direct involvement with this project.

Thank you.

Cam Bonertz
Graduate Student

Appendix G

Consent Form (Participants)

The effect of auditory instruction on upper limb motor performance and learning for persons with Down syndrome.

Principal Investigator: Cameron Bonertz, (780) 492-0578
Graduate Student, Faculty of Physical Education and Recreation

Co-Investigator: Dr. Brian Maraj, (780) 492-8649
Professor, Faculty of Physical Education and Recreation

Do you understand that you have been asked to participate in a research study?	Yes	No
Have you read and received a copy of the information sheet?	Yes	No
Do you understand the benefits/risks involved in taking part in this study?	Yes	No
Do you have any questions about the study?	Yes	No
Do you understand that you are free to refuse to participate or to withdraw from this study at any time, without consequence, and that your information will be withdrawn at your request?	Yes	No
Do you understand that your information will be private?	Yes	No
Do you understand who will have access to your information?	Yes	No

The study has been discussed with me and all my questions have been answered. I understand that additional questions regarding the study should be directed to the investigator listed above.
I agree to take part in this study.

Signature of Participant	Date
Witness	Date
Investigator	Date

Appendix H

Participant Assent Letter

The effect of auditory instruction on upper limb motor performance and learning for persons with Down syndrome.

You will be doing a pointing task on the computer. The screen will have pictures of a bell, a trumpet, a whistle, and a circle on it. You will need to use a mouse to click on these pictures in order. I will use four different ways to teach you the order. I will **show** you by making the pictures light up. I will **tell** you by saying the names of the pictures. I will play **music** from the instruments. I will play **sounds** than sound like beeps. The order I teach you will change each time but I will only teach you one way at a time. After I teach you the movement pattern I will ask you to move the mouse from the circle to the shapes as fast as you can. Try not to make mistakes. You will do this several times and then we will take a break. After our break I will teach you the order again. You will have less movement patterns to do this time. I will only need your help for 2 hours and then you can go home. Would you like to do this task?

YES NO

Your Name: ________________________________

Appendix I

Consent Form (Parents/Guardians)

The effect of auditory instruction on upper limb motor performance and learning for persons with Down syndrome.

Principal Investigator: Cameron Bonertz, (780) 492-0578
Graduate Student, Faculty of Physical Education and Recreation

Co-Investigator: Dr. Brian Maraj, (780) 492-8649
Professor, Faculty of Physical Education and Recreation

Do you understand that your child or ward has been asked to be in a research study?	Yes	No
Have you read and received a copy of the information sheet?	Yes	No
Do you understand the benefits/risks involved in this study?	Yes	No
Do you have any questions about the study?	Yes	No
Do you understand that your child or ward is free to refuse to participate or to withdraw from this study at any time, without consequence, and that their information will be withdrawn at your request?	Yes	No
Do you understand that your child or ward's information will be private?	Yes	No
Do you understand who will have access to your child or ward's information?	Yes	No

The study has been discussed with me and all my questions have been answered. I understand that additional questions regarding the study should be directed to the investigator listed above. I certify that I have read this consent form and that by completing this signature below I have given consent for the participant to participate.

Signature of Parent/Guardian Date

Witness Date

Investigator Date