Counting and Sequential Processing in Children with Down Syndrome and Typically Developing Children

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Abstract
The development of numerical skills in children with Down syndrome is an area of research that has been neglected in the literature despite overwhelming evidence of its importance, both pedagogically, and for everyday functioning. The present study examines two important sub-skills of numeracy. Twelve boys with Down syndrome were compared to 24 typically developing boys (matched on verbal mental age and on chronological age) on two novel, computerized tasks designed to measure sequential processing and counting. Boys with Down syndrome performed comparably to both groups of typically matched controls on the sequential task. However, differences emerged when boys with Down syndrome were required to point and attribute meaning to each step on the counting task. These findings offer novel insights into the development of number skills and provide important data that can aid in the creation of syndrome-specific education strategies to maximize the potential of children with Down syndrome.
Abstrait

Le développement des compétences numériques chez les enfants atteints du syndrome de Down est un sujet de recherche négligé dans la littérature en dépit de l'évidence claire de son importance, à la fois du côté pédagogique et pour le fonctionnement quotidien. L'étude présente examine deux habiletés importantes de la compétence numérique. Douze garçons atteints du syndrome de Down ont été comparés à 24 garçons se développant normalement (égalés pour leur âge mental verbal et pour leur âge chronologique) pendant deux nouvelles tâches informatisées conçues pour mesurer les habiletés de traitement séquentiel et de comptage. Les garçons atteints du syndrome de Down ont performé de façon comparable aux deux groupes de contrôle dans la tâche de traitement séquentiel. Cependant, des différences émergèrent quand les garçons atteints du syndrome de Down devaient pointer et attribuer un sens à chaque étape pendant le comptage. Ces résultats offrent un nouveau regard sur le développement des compétences numériques en plus de fournir d’importantes données pouvant aider à la création de stratégies éducationnelles spécifiques afin de maximiser le potentiel des enfants atteints du syndrome de Down.
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CHAPTER I

Introduction

Recent years have witnessed an increasing appreciation for the convergence of the fields of developmental psychopathology and the cognitive neurosciences. This immersion has allowed for a more intricate and accurate understanding of how typical and atypical populations develop and how their unique cognitive makeup may play a crucial role in the varying developmental pathways that ensue. However, one area that has yet to be fairly represented in this research, most notably in atypical populations, is the development of numerical cognition. In particular, a syndrome that has received continued increasing attention over the last decade is Down syndrome but a cognitive domain that has been neglected in this literature is the development of early counting skills. This apparent lack of interest is surprising and worrying given the unquestionable influence of mathematical skills for future success in industrialized societies (Geary, 2000). The ability to be financially independent is critical, to live a somewhat independent adult lifestyle; for example, holding a bank account, paying bills, and figuring out how much change one should receive after paying for a purchase. Furthermore, the development of numerical competencies is related to quality of life as an adult in atypical populations, namely Down syndrome (Faragher & Brown, 2005). The ability to take on these financial type tasks develops through the acquisition of early math and counting skills; unfortunately, these skills tend to be overlooked in the educational realm in favour of a focus on reading and language (Porter, 1999; Nye, Clibbens, & Bird, 1995; Nye & Bird, 1996; Nye, Fluck, & Buckley, 2001). There is no doubt that reading and language are necessary components of a child’s education,
nevertheless, mathematical competence remains a priority, especially in terms of its fundamental impact on one’s ability to lead an independent life. Numerical cognition is an area of research that is in need of attention due to the particular vulnerability of this cognitive domain in children with Down syndrome. A developmental approach is utilized in hopes of gaining a true appreciation for the basic processes underlying numerical abilities and how these differ in children with Down syndrome and typically developing children.

Typical Development of Numerical Cognition: Sequential Processing and Early Counting Skills

In typically developing children, numerical skills begin early. Wynn (1992; 1998) has shown that young infants are able to discriminate between small numbers and to engage in numerical computations. By about 18 months of age, infants show an understanding of simple ordinal relationships, for example that a set of 2 items is more than a set of one item but less than a set of three (Strauss & Curtis, 1994). In contrast, Xu (2003) more recently provides evidence that 6-month old infants although unable to discriminate between small numerosities (1 vs. 2 and 2 vs. 4) are successful in discriminating larger numerosities (4 vs. 8, 8 vs. 16, and 16 vs. 32) when the ratio between the numbers is held constant (also see Xu & Spelke, 2000). By the age of 4 years, typically developing children can count up to four items, and by about 5-6 years of age they can count up to 15 (Shalev & Gross-Tsur, 2001). As numerical development progresses into calculation, the child begins to establish a repertoire of numerical facts and must learn to use formal codes and algorithms of a given culture. At this stage, proficient numerical processing typically becomes more dependent upon effective short-
term or working memory (WM) processing (Geary, Brown, & Samanayake, 1991; Siegal & Ryan, 1989).

An essential step in developing basic numerical skills involves understanding how counting is related to number and learning the meaning of number words used in counting. Wynn (1992) has shown that children learn the number words up to "two" or "three" early in development, but acquire the meaning of larger number words only in conjunction with their growing understanding of cardinality (i.e., that the last number word used while counting a set of objects represents the number of objects in the set). This process can take up to a year in typically developing children. Therefore, without the acquisition of this principle, development of further mathematical skills cannot proceed.

The sequencing of primary counting behavior establishes a setting for an understanding of cardinality. Bermejo et al. (2004) have posited the existence of six levels towards an understanding of cardinality, where there is an interaction between counting and cardinality alongside a child's developmental level. According to this model, only the second, third, and fourth levels are related to counting, whereas the higher levels are accomplished irrespective of counting. For example, when presented with the "How Many Task", children at the first level demonstrate their lack of knowledge by providing random responses, sometimes without quantitative reference. At the second level, children begin to respond with a number-word sequence, but they do so without indicating individual items. This manner of responding, however, symbolizes their maturing sense of the relationship between counting and cardinality. The third level is characterized by a full count-cardinal reference. In particular, children
count individual objects in sequence. At the fourth level, children adhere to the last-word rule by answering with the last number-word in a sequence. At the fifth level, children make a partial reference to cardinality by answering with the highest number-word in counting. However, not until children achieve the sixth level of understanding do they reliably provide an accurate cardinal response. Therefore, children’s responses in the “How Many Task” are constrained by their developmental limits (Bermejo, 1996). Specifically, the development of knowing how to count and understanding why one counts provides the foundation for exact number representation (Ansari et al., 2003).

Counting is error prone due to memory requirements, such as forgetting which items have already been counted. Alongside memory, another aspect of cognition necessary for pre-requisite counting milestones (Gelman & Cohen, 1988) is sequential information processing (see Table 1). Initially, counting requires the co-ordination of two sequences of behaviour, which include pointing to individual objects in turn and reciting the sequence of number words in synchrony while pointing. Subsequently, any difficulties in executing this sequence of behaviour typically results in deficient counting skills (Trick & Pylyshyn, 1994). As such, counting is an attention-based process that involves a number of stages, where increased response times are attributed to greater numbers of presented stimuli (Trick & Pylyshyn, 1994). Therefore, reliable and accurate counting is accounted for by well-developed attention and memory cognitive structures that are activated along with sequencing skills for counting. Therefore, it seems highly probable that any difficulty in executing sequences of response would impact upon counting behaviour, either through impaired sequential
responding in one or both modalities, or in a failure to co-ordinate the two sequences of behaviour.

Table 1 (Gelman & Cohen, 1988)

_Pre-Requisite Counting Milestones_

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. One-to-one principle</strong></td>
<td>The child uses only one number word for each object. Younger children may skip objects or to say two number words for the same object.</td>
</tr>
<tr>
<td><strong>2. Stable order principle</strong></td>
<td>The number words are used in fixed order. The child has memorized the correct sequence in counting, the length of which increases with age.</td>
</tr>
<tr>
<td><strong>3. Order irrelevance principle</strong></td>
<td>It does not matter which object is assigned a number first, but all objects must be counted.</td>
</tr>
<tr>
<td><strong>4. Cardinality principle</strong></td>
<td>The child realizes that the last number word used is the number of objects in a set.</td>
</tr>
<tr>
<td><strong>5. Abstraction principle</strong></td>
<td>The counting procedure can be applied to all kinds of things, and even to a group of items presented in sequence.</td>
</tr>
</tbody>
</table>

**The Importance of Identifying Syndrome-Specific Signatures in Numerical Development**

In contrast to the existing body of knowledge on typically developing children, there remains a considerable gap in our understanding of the development of basic numerical skills in atypical populations. Although many developmental disorders report deficits in numerical cognition (e.g. Williams syndrome, Fragile X syndrome, and Down syndrome), relatively few studies have systematically investigated the nature of this impairment. Even fewer studies have traced the developmental trajectory, in order to
discover whether such deficits are due to slower progress on the same trajectory as typically developing children or if there are differences in the actual process involved. Children with developmental disorders may demonstrate skills equivalent to typically developing children of a similar mental age but more detailed analysis may demonstrate the processes by with they achieve such competence are different from those of typically developing children. The charting of periods of development when marked changes in performance occur is a primary step in providing a precise map of efficiency of functioning in evaluating performance as typical, delayed, or syndrome specific.

A flurry of recent studies has documented syndrome-specific profiles of cognitive strengths and weaknesses that go beyond the general effects of mental retardation per se. For example, the cognitive profile of Williams syndrome, which is a genetic disorder caused by the deletion of genetic material from the region q11.2 of chromosome 7, is characterized by a marked strength in verbal cognition and a serious impairment in nonverbal processing. This syndrome can be compared alongside Fragile X syndrome, which is caused by a switching off of the Fragile X Mental Retardation-1 (FMR1) gene on the X chromosome and presents with a profile of mild to severe mental retardation. Individuals with Fragile X syndrome have relative strengths in language, which accompany relative weaknesses in visuo-spatial cognition (Cornish, Munir, & Cross, 1999; Freund & Reiss, 1991). In addition, a syndrome that has received continued increasing attention over the last decade is Down syndrome, which is due to errors during meiosis, generating three rather than two copies of chromosome 21. Wishart and Duffy (1990) show that for young children with Down syndrome, overall delay in general cognitive scores masks an uneven pattern of performance with visuo-
spatial skills exceeding scores in the verbal domain. In addition, Wilding et al. (2002) and Scerif et al. (2004) found that children with Fragile X syndrome, as compared to children with Down syndrome, had a greater problem in moving on from a successful response in a sequential task.

*Down Syndrome & Cognitive Functioning*

Down syndrome is the world's most common genetic cause of mental retardation, with a prevalence of 1 per 800 births (Hayes & Barshaw, 1993). In most cases, the syndrome is due to errors during meiosis, generating three rather than two copies of chromosome 21. As the embryo develops, the extra chromosome is replicated in every cell of the body; this faulty cell division is responsible for 95 percent of all cases of Down syndrome. In some children with Down syndrome the triplication process occurs in only part of chromosome 21, which is referred to as partial trisomy 21. Finally, 1-2% of individuals with Down syndrome have mosaicism, which is due to the translocation of an extra piece of the long arm of chromosome 21, resulting in a "mosaic" pattern of the cells. In all cases, this additional genetic material alters the course of development and causes the characteristics associated with the syndrome.

Down syndrome is characterized by mild to severe mental retardation (IQ range between 40-60), problems of inattention and hyperactivity (Carr, 1988; Coe et al., 1999; Clark & Wilson, 2003; Wilding et al., 2002), and differing strengths and weaknesses across and within cognitive domains. Individuals with Down syndrome demonstrate relative strengths in visuospatial cognition and visuo-perceptual integration (Wang & Bellugi, 1994) accompanied by relative weaknesses in language (Wishart & Duffy, 1990), receptive vocabulary (Cichetti & Ganiban, 1990; Abbeduto et al., 2003), and...
visuo-constructive skills (Cornish et al., 1999). Memory difficulties are also a core feature of Down syndrome with deficits in short-term memory. (Jarrold & Baddeley, 2001; Jarrold, Baddeley & Phillips, 2002). Finally, children with Down syndrome demonstrate less sequential processing problems than, for instance, children with FXS (Wilding et al., 2002), therefore it will be interesting to determine whether they show a less acute problem in basic counting skills.

Table 2

*Relative Strengths and Weaknesses in Cognitive Functioning in Down syndrome*

<table>
<thead>
<tr>
<th></th>
<th><strong>Attention &amp; Inhibition</strong></th>
<th><strong>Language &amp; Vocabulary</strong></th>
<th><strong>Memory</strong></th>
<th><strong>Spatial Cognition</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
<td>- Sequential processing of non-verbal information</td>
<td>-Non-verbal social communication</td>
<td>-Visual-spatial short-term memory</td>
<td>-Visuo-perceptual integration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Vocabulary comprehension</td>
<td>-Implicit memory</td>
<td>-Visuo-spatial cognition</td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td>- Attention &amp; Concentration</td>
<td>-Delayed expressive &amp; receptive language</td>
<td>-Short-term memory for verbal information</td>
<td>-Visuo-construction of meaningful designs</td>
</tr>
<tr>
<td></td>
<td>- Sequential processing for verbal information</td>
<td>-Language fluency</td>
<td></td>
<td>-Visual construction of abstract designs</td>
</tr>
<tr>
<td></td>
<td>- Auditory information processing</td>
<td>-Syntax Comprehension</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Down Syndrome and the Development of Numerical Cognition*

A cognitive domain that has been underrepresented in research on Down syndrome is the development of early counting skills. While numerical ability has been
Counting relatively well documented in Williams syndrome (e.g., Ansari et al., 2003; Howlin, Davies, & Udwin, 1998; Levitin et al., 2003) and Turner syndrome (Mazzocco, 1998, 2001; Rovet, Szekely, & Hockenberry, 1994) little is known about the subtle aspects of numerical ability unique to Down syndrome. Down syndrome may be the most extensively researched of all developmental disorders, however the majority of research has focused on language and reading skills in this population (Kennedy & Flynn, 2003; Byrne, MacDonald, & Buckley, 2002; Fletcher & Buckley, 2002). This remains true despite the fact that the development of number skills is a crucial prerequisite for academic achievement and quality of life as an adult. This point is emphasized by Faragher & Brown (2005) who have used the quality of life approach to justify and guide the lifelong development of numeracy in individuals with Down syndrome. They note that numerical preparation, which is essential for a long and satisfying adulthood should begin in early childhood and continue in school. Most studies on numerical ability in children with Down syndrome suggest that children with Down syndrome underachieve on number tasks compared with other skills, such as reading (Carr, 1988; Byrne, 1997; Sloper, Turner, Cunningham, & Knussen, 1990).

Research suggests that children with Down syndrome have deficits in working and short-term memory due to a specific deficit in the phonological loop component of Baddeley & Hitch's 1974 model of working memory (Jarrold, Baddeley, & Philips, 1999) and experience particular difficulties with encoding and storing information presented in the auditory channel (Marcell, Harvey, & Cothran, 1988; Marcell & Weeks, 1988; Hulme & Mackenzie, 1992). This may make learning new words, including number words difficult (Laws, MacDonald, & Buckley, 1996). Jarrold,
Cowan, Hewes, & Riby (2004) explored the degree of short-term memory deficits among individuals with Down syndrome and Williams syndrome. Among individuals with Williams syndrome, an impairment in serial recall could be explained in terms of a general slowing in speech rate. In contrast, this could not account for the extent of impairment in individuals with Down syndrome. Moreover, in a replication of Porter’s (1996) study the counting skills of children (7-13 years of age) with Down syndrome matched to children with severe learning difficulties (without Down syndrome). These groups were matched based on scores from the British Picture Vocabulary Scale (BPVS). Porter (1999) employed the “How many?” task, which involves an understanding of the one-to-one principle and being able to respond to the cardinal question. Children had to produce number strings (stable conventional count list), tag each object once and only once (one-to-one correspondence), and answer the “how many question” by repeating the last tag (cardinal response). The authors found that children with Down syndrome perform in direct contrast to those with severe learning disabilities as they had better one-to-one correspondence but were outperformed on stable conventional order of number words. Porter (1999) contend that this weakness on the part of children with Down syndrome may be linked to problems with acquisition of vocabulary due to auditory memory difficulties. Furthermore, this memory problem may also be connected to their poor sequencing skills.

The importance of adhering to a developmental perspective when researching numerical cognition is supported heavily by studies that have followed the developmental trajectories of atypical populations from infancy through to adulthood. This method provides the foundation necessary to differentiate one syndrome from
another and from typically developing children and to accurately account for the
differences that arise. The significance of these studies is that they question the notion
that one can predict later adult outcomes from infant performance and vice versa. In two
studies by Paterson (2001; 2006), the performance of children and adults with Williams
syndrome and Down syndrome was compared on various numerical tasks. They found
that the pattern of performance of infants with Down syndrome and Williams syndrome
could not be derived from the pattern of proficiencies and impairments in adults with
Down syndrome and Williams syndrome. They found that infants with Williams
syndrome performed comparably to chronological age (CA) matched controls whereas
infants with Down syndrome were not even able to perform at a level comparable to
their mental age (MA) matched controls. However, the older children and adults with
Down syndrome outperformed the Williams syndrome group in terms of numerical
competence. These studies highlight the crucial role of taking on a developmental
perspective to acquire a more detailed understanding of the underlying processes
involved in the development of numerical cognition and how this changes throughout
the lifespan in individuals with Down syndrome and impacts upon further development.

Nye, Fluck, & Buckley (2001), examined the procedural counting ability
(counting sets of toys) and conceptual understanding of cardinality (giving sets of toys)
in a group of children with Down syndrome (CA = 3.5 to 7 years, MA = 2 to 4 years)
and a group of non-verbal mental aged matched typically developing children (CA = 2
to 4 years, MA = 2 to 4 years). Children were also asked to say the count word sequence
aloud, to assess sequence production independent from object counting. It was found
that compared to their typically developing counterparts, children with Down syndrome
produced significantly less number words overall, shorter standard number sequences, and had less success at counting larger sets of items. Moreover, neither group of children demonstrated an understanding of cardinality. In a follow up study, which charted the development of counting skills in these children, Nye (2003) explored count word production, object counting, and understanding of cardinality at 3 points in time over a 1 and a half-year period. Results revealed that there were significant differences between the children with Down syndrome and typically developing children on production of count word sequences and word count vocabularies but not on object counting and cardinal understanding, which develop as predicted by their non-verbal MA; these findings were consistent at each test point.

Stith and Fishbein (1996) investigated the ability to count coins and compare small amounts of money among children and adolescents with Down syndrome, children with mental retardation (MR) of unknown etiologies, and typically developing first graders. The two groups of children with mental retardation had far greater difficulty with the tasks than typically developing children, with no considerable differences in performance between the two. These findings again suggest that etiology does not play a role in the basic counting skills and that numerical deficits may not be syndrome specific.

In a study by Irwin (1991), eight individuals with Down syndrome, aged 11 to 13 years, were taught to use a more advanced adding technique, termed counting-on, during a five-day training program. Multiple baseline measures showed that all participants in this study were able to master the technique of counting-on within 1 week. All the students generalized the use of the technique to materials other than those
used in instruction when assessed at the end of the teaching period and all but two
continued to do so 6 months later. These results suggest that counting-on ability by
children with Down syndrome may reflect style of teaching, rather than a deficit that is
unique to Down syndrome.

*Relationship between Numerical Development and Receptive Language (VMA) in Down Syndrome*

Receptive language measures are one of the most commonly used matching tools
in studies investigating numerical competencies in atypical populations. For example,
Ansari et al. (2003) presented a comprehensive investigation of low-level number
faculties involved in the development of atypical trajectories. They compared the
performance of children diagnosed with William’s Syndrome with typically developing
children. They found that in typical development, specific cognitive capacities guided
the ability to determine exact quantity, rather than overall intellectual ability.
Furthermore, despite an obvious strength in verbal ability, the performance among
children diagnosed with William’s Syndrome was only at a level expected for their
visual-spatial mental age comparisons, approximately 3 to 4 years of age. Therefore,
among their tasks tapping numerical conception, results indicated that only visual-
spatial competence accounted for success among typically developing children, whereas
greater verbal ability contributed to a higher success rate among children with William’s
Syndrome (Ansari et al., 2003).

The utilization of measures of receptive language when studying numerical
cognition in Down syndrome may be critical in determining whether performance is
syndrome specific or whether it is due to a general delay that leads to poor versus
successful functioning on a given task. This is of particular importance when studying children with Down syndrome because they do have a specific deficit in the verbal domain (Abbeduto et al., 2003). Gelman and Cohen (1988) researched both the implicit and explicit numerical understanding of children with Down syndrome and typically developing children without the inclusion of a measure of receptive vocabulary. Findings from this study highlight qualitative differences in the way in which the groups approached the counting tasks. In particular, the majority of children with Down syndrome demonstrated only rote learning while the typically developing children exhibited both implicit and explicit understanding of number. From this they concluded that children with Down syndrome are unique in terms of these numerical deficits. However, Caycho, Gunn, and Siegel (1991) employed Gelman and Cohen’s 1988 modified counting task, conducting a similar study with the inclusion of a measure of receptive vocabulary (PPVT-R) to match the participants and came to a very different conclusion. In contrast to Gelman and Cohen (1988), they found no significant differences between the counting behaviour of the children with Down syndrome to preschool children of similar developmental age. They contend that children with Down syndrome can make use of counting principles and that competence in counting is related to receptive language ability rather than to syndrome specific deficits in numerical cognition.

Nye, Clibbens, & Bird (1995) investigated the relationship of both general ability and receptive language with numerical competence in children with Down syndrome. They employed 4 different numerical measures, which were all significantly positively correlated to each other. They also found that receptive language was
significantly positively correlated to these numerical skills. This suggests that children with Down syndrome can be guided by these necessary counting principles and that developmental level, rather than the syndrome itself, is associated with counting behaviour.

Another study compared the receptive language, expressive language, and theory of mind in individuals with Down syndrome to individuals with Fragile X syndrome to determine which domains of functioning are especially impaired in individuals with Down syndrome and which aspects of the linguistic and cognitive profile of Down syndrome are syndrome-specific (Abbeduto, Pavetto, Kesin, Weissman, Karadottir, O'Brien, & Cawthon, 2001). They found that receptive language, expressive language, and theory of mind were more severe problems for Down syndrome in comparison to their overall cognition and more severe deficits than in Fragile X syndrome. Thus, if receptive language does play a crucial role in numerical competence it follows that children with Down syndrome may not fair as well on numerical type tasks.

The aforementioned research clearly implicates the role receptive language plays in terms of numerical competence and later mathematical success. It may be that despite the proficient visuo-spatial abilities of individuals with Down syndrome, this may not benefit them on tasks of numerical cognition as it does in typically developing children because successful performance has been shown to be more dependent on verbal skills in atypical populations, which is a particular weakness for them.

Present Study

Although many developmental disorders report deficits in numerical cognition (e.g. Williams syndrome, Fragile X syndrome, Down syndrome, Turner's syndrome),
relatively few studies have systematically investigated the nature of this impairment. Fewer still have traced the developmental trajectory, in order to discover whether such deficits are due to slower progress on the same trajectory as typically developing children or to differences in the processes involved. Atypically developing children may demonstrate skills equivalent to normally developing children of a similar mental age, but more detailed analysis may demonstrate that the processes by which they achieve such competence are different from those of typically developing groups. Differences such as this at one stage of development will impact on further development. Therefore tracing the developmental trajectory is particularly effective in revealing the detailed processes involved in demonstrating such a skill.

For the present study boys with Down syndrome were matched to two groups of typically developing boys on chronological age (CA) and verbal mental age (VMA). A novel sequential processing task was devised analogous to counting, but without actual counting, to determine whether weakness in performing a sequence of responses might impair the ability to count in boys with Down syndrome. Furthermore, a counting task was also created which assesses the ability to coordinate pointing to objects and reciting the name of each number object in turn. A comparison of these two tasks will allow for the teasing apart of the development of counting skills and to investigate where deficits in performance may become apparent. It follows that while children with Down syndrome may be successful when performing the two behaviours necessary for successful counting in isolation, which include following a sequence of steps to reach a desired goal (Treasure Task) and counting aloud, difficulty may arise when they are asked to successfully coordinate both of these behaviours (Counting Task). Surprisingly,
no studies have been located which address this possibility in children with Down syndrome.

Aims, Objectives, and Hypotheses

Aims. The overall aim of this study is to chart the developmental trajectories of cognitive development in children with Down syndrome to provide information for the creation of syndrome-specific educational programs. Furthermore, the present study seeks to elucidate a pattern of proficiencies and deficiencies in basic numerical ability among male children with Down syndrome. Male children with Down syndrome were matched to two control groups of typically developing male children based on chronological age (CA) and developmental level (verbal mental age) to assess for global deficits or syndrome specific deficits. Specifically, it will aim to compare the performance of boys with Down syndrome to that of typically developing matched controls on sequential processing, counting, and cardinal understanding.

Objectives. One specific objective is to identify the nature and extent of numerical understanding in children with Down syndrome and whether there are any deficits that can be viewed as evidence of a general cognitive delay or a difference in performance. The second objective is to assess the developmental changes in number comprehension in order to determine whether differences are static across developmental time or whether they change as a function of development itself. Identifying patterns of proficiencies and deficiencies will allow families and teachers to gain appropriate help from support services more easily as well as a detailed profile of deficits, which will ensure that the help received is better targeted to the needs of children with Down syndrome. An important long-term goal of this research is the
identification of syndrome-specific cognitive aspects of numerical ability for the design of appropriate and timely education strategies that will maximize the learning potential of children with Down syndrome.

**Hypotheses.** Hypothesis #1: Children with Down syndrome will perform comparably to typically developing children matched on verbal mental age (VMA) on the treasure task, which measures sequential processing and requires children to follow a series of steps to reach a goal. It was hypothesized that both reaction time and error rates would be comparable between the two groups.

Hypothesis #2: Children with Down syndrome will perform comparably to typically developing children matched on chronological age (CA) on the treasure task, which measures sequential processing and requires children to follow a series of steps to reach a goal. It was hypothesized that both reaction time and error rates would be comparable between the two groups.

Hypothesis #3: Significant differences would emerge between boys with Down syndrome and verbal mental age (VMA) matched typically developing boys on the counting task because children with Down syndrome, although able to follow a sequence of steps and count in isolation, would have difficulty coordinating these two behaviours and giving an accurate cardinal response. Whereas typically developing boys should be able to successfully complete this task without difficulty by the same age.

Hypothesis #4: Even greater significant differences would emerge between boys with Down syndrome and chronological age (CA) matched boys on the counting task than on the treasure task and these differences would again be greater than the differences apparent between boys with Down syndrome and verbal mental age (VMA).
matched boys. These typically developing boys should be advanced at this task (i.e. very few errors, faster reaction times, and consistently accurate cardinal responses) and well beyond that of boys with Down syndrome.
CHAPTER II

Method

Participants

A total of 24 typically developing boys and 12 boys with Down syndrome were recruited from Montreal, Quebec; Hamilton, Ontario; and London, Ontario. For the analyses, 12 typically developing boys were matched to boys with Down syndrome on verbal mental age (group TD1) and 12 were matched to boys with Down syndrome on chronological age (group TD1). The matching procedure can be found in Table 3.

Group 1: Boys with Down syndrome. Group 1 consisted of 12 boys with DS recruited through organizations and schools in London, Ontario and Montreal, Quebec. The age range for boys with Down syndrome was 7 to 11 years old. The mean chronological age of boys with Down syndrome was 8 years, 11 months (SD = 1 year, 3 months). The mean verbal mental age (VMA) for boys with Down syndrome was 4 years, 2 months (SD = 1 year, 3 months).

Group 2: Typically Developing Control Group (TD1). Group 2 consisted of 12 typically developing boys recruited from mainstream schools in Hamilton, Ontario and Montreal, Quebec. These children were matched to the boys with Down syndrome on verbal mental age (VMA) and are therefore biologically younger in age than the boys with Down syndrome. For group 2, the age range was 4 to 6 years old and mean chronological age was 5 years, 5 months (SD = 9 months). The mean verbal mental age for this group was 4 years, 10 months (SD = 9 months).

Group 3: Typically Developing Control Group (TD2). Group 3 consisted of 12 typically developing boys recruited from mainstream schools in Hamilton, Ontario and
Montreal, Quebec. Children were matched to the boys with Down syndrome on chronological age and are therefore biologically the same age as the syndrome group. For group 3, the age range for group was 4 to 11 years old and mean chronological age was 8 years, 7 months (SD = 2 years, 6 months).

Table 3

**Summary of Three Groups**

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Matched On:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Study Group:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down Syndrome</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td><strong>2) Control Group 1:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typically Developing (TD1)</td>
<td>12</td>
<td>Verbal Mental Age</td>
</tr>
<tr>
<td><strong>3) Control Group 2:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typically Developing (TD2)</td>
<td>12</td>
<td>Chronological Age</td>
</tr>
</tbody>
</table>

The means and standard deviations of CA and VMA scores for typically developing boys and boys with Down syndrome included in the analysis can be found in Table 4.
Table 4

Background Data for Boys with Down syndrome and Typically Developing Boys

<table>
<thead>
<tr>
<th>AGE (in months)</th>
<th>Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Study Group</td>
</tr>
<tr>
<td></td>
<td>DS</td>
</tr>
<tr>
<td>Mean Chronological Age (SD)</td>
<td>107.58 (14.51)</td>
</tr>
<tr>
<td>Mean Verbal Mental Age (SD)</td>
<td>49.75 (14.81)</td>
</tr>
</tbody>
</table>

Measures

Participants were administered a measure specifically designed to assess developmental level as well as two newly developed, novel computerized tasks to assess sequential processing and counting judgment (See Table 5).

Developmental Level

Participants were assessed based on their overall mean performance on one standardized measure of verbal ability.

Verbal Mental Age Measure. Developmental matched control children were matched to children with Down syndrome on their overall mean performance on a test of verbal mental ability, as assessed by the Peabody Picture Vocabulary Test (PPVT, Form A; Dunn & Dunn, 1987). The Peabody Picture Vocabulary Test-III is a receptive vocabulary test that consists of 204 vocabulary items of increasing difficulty. Children are shown a series of four black and white illustrations and are then required to select the picture that best represents the meaning of an orally presented word. Each word is read aloud by the experimenter. The task is an individually administered, un-timed, and
norm-referenced test. The child is awarded one point for each correct answer and zero points for each incorrect answer. From this measure a verbal mental age score was derived. This test takes approximately 10-15 minutes to complete.

Participants’ MA scores were calculated in terms of verbal mental age (VMA) from the PPVT. VMA was calculated from the total raw score on the PPVT using the norm scores from the examiner’s manual of the test.

This project is part of a broader study examining differences in mathematical understanding among boys with Fragile X syndrome, boys with Down syndrome, and typically developing boys. Previous research demonstrates that traditional standardized IQ batteries, such as the Weschler Intelligence Scales, may not accurately reflect intellectual or developmental level in atypical populations who present with mental retardation (see Cornish et al., 2004 for a review). Therefore, in order to assess verbal abilities the aforementioned measure was chosen as a result of its high correlation with IQ as well as its enhanced capability to provide more accurate and fair comparisons between atypical and typical populations. More specifically, children with Down syndrome present with an apparent weakness in receptive vocabulary, thus, a measure of receptive vocabulary will be a fair and accurate tool to assess whether differences are due to the syndrome itself or are related to poorer receptive skills.

*Sequential Processing Task*

The *Find the Treasure Task* (Wilding & Cornish, 2004) assesses a child’s ability to carry out a simple series of steps to attain a goal. The display screen shows five stepping-stones in the sea leading to an island on which there is a hidden treasure chest (Refer to Figure 1). Using touch screen technology, each child is required to point to
each stepping-stone, by touching them on the screen, which finally leads to the treasure chest. When the child selects the final stepping-stone, the chest can be opened to find the treasure. The task is comprised of six separate practice and experimental conditions, where the target displays are varied according to presentation (i.e., simultaneous or sequential), the spacing of the targets (i.e., regular or irregular), as well as feedback type (no feedback or vanish). Distracter stimuli are present on each trial. Following a set of verbal instructions, each child is administered six practice trials and six corresponding test trials. Responses are recorded in terms of mean time per touch, the number of false alarms (i.e., touches on distracter items or background), repetitions, and returns. The task takes approximately 15 minutes to complete.

Figure 1. Treasure Task

Counting Task

The Counting Task (Wilding & Cornish, 2004) is a novel computerized task consisting of varying numbers of circles shown on a computer screen (Refer to Figure 2). Using touch screen technology, the child is instructed to click on these circles (in any
order) while counting aloud. There are a total of 5 trials per run for 3 to 7 circles to be counted, which amounts to 20 trials altogether. The sequence of clicks is recorded as well as the time it takes in total and between each touch of a circle. Subsequently, a variety of measures of performance were extracted and analyzed. The counting aloud was recorded on disc then the sequences and times were extracted. Two parameters of the display were varied: regularity, with the circles in a straight horizontal line (regular) or randomly varied in their vertical position to create an irregular display; feedback with no change after a click on a target or the target disappeared after being touched. Hence there were four conditions always given in the same order (regular no feedback, regular with change feedback, irregular with no feedback, irregular with change feedback).

Figure 2. Counting Task
### Table 5

**Summary of Measures by Domain**

<table>
<thead>
<tr>
<th>Domains</th>
<th>Tasks and Description</th>
<th>Example</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Verbal Mental Ability</td>
<td>- [PPVT-III] (Dunn &amp; Dunn, 1987)</td>
<td>“Now look at all the pictures on the page.” “Point to ball.” or “What number is ball.”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- A measure of receptive vocabulary for English and a screening test of verbal ability.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Sequential Processing</td>
<td>- Find the Treasure Task (Wilding &amp; Cornish, 2004)</td>
<td>The display screen shows five stepping-stones in the sea leading to an island on which there is a hidden treasure chest to open. Using a touch screen, the child is to point to each stepping stone until he/she reaches the last stepping stone and the chest can be opened to find the treasure.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Measures a child’s ability to carry out a simple series of responses to attain a goal.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Counting &amp; Cardinal Understanding</td>
<td>- Counting Task (Wilding &amp; Cornish, 2004)</td>
<td>Using touch screen technology, the child touches the circles (in any order) while counting out loud. The sequence of clicks is recorded as well as the time it takes in total between each touch of a circle.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Measures a child’s ability to point while counting aloud</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Procedure

Information packages were sent to numerous school boards and organizations in the Montreal, Hamilton, and London area for permission to conduct the study. Separate English and French school boards agreed to participate in the study. Subsequently, additional information packages were provided to individual principals of elementary schools within those educational boards and to different heads of organizations. Two elementary schools in the Montreal area and the Hamilton area school agreed to participate as well as a school for children with developmental disorders in Montreal and in London. An information package was provided to all the aforementioned places, which outlined the goals and procedures involved in the research, as well as a copy of the approved ethics form from the McGill University Ethics Committee (see Appendix A). The schools’ and organizations’ administration proceeded to send information packages to all parents of male students between the ages of 5 and 11 years. These packages contained parental information sheets explaining the research objectives and procedural requirements involved in the study and a parental consent form (see Appendix B). Additionally, there was a booklet created specifically for the families and their children to read together, which explained the tasks in a fun and simple fashion. Only the children whose parents signed a consent form indicating that they agreed to allow their child to participate were included in the study.

All participants were tested individually in a small and quiet room free from distraction in two or three separate 50-minute sessions. Children were explained the purpose and procedures of the study using developmentally appropriate language, and only those who verbally assented to participate were included in the study (see
Appendix C). School and organization personnel received a group analysis of the participating children’s strengths and weaknesses for both numerical and sequential ability, as well as recommendations to meet the specific educational needs of these children.
CHAPTER III

Results

Data was examined using the Statistical Package for the Social Sciences (SPSSv.11.0). Descriptive statistics (i.e., mean, standard deviation, and standard error of the mean) were computed across all measures. Univariate analyses of variance (ANOVA) were performed to look at the differences between groups on chronological age (CA) and verbal mental age (VMA). In addition, parametric inferential statistics (i.e., Repeated Measures Mixed ANCOVA) were used to test for significant differences in scores on measures of sequential and numerical functioning across participant groups and tasks. Significant effects were followed up by separate one-way ANOVA’s across the different variables followed by post-hoc Scheffe on the dependent variable of interest as a function of group and task. Finally, correlational analyses were used (i.e., Pearson Product Moment) to assess the strength of association between chronological age (CA) and task performance by group membership. Violation of the assumption of sphericity was tested for each ANCOVA using Mauchly’s test of Sphericity. If significant, the Greenhouse-Geisser corrections were applied to those analyses. Finally, to reduce the likelihood of Type I errors, the Bonferroni correction test was used where only those results meeting an alpha level of 0.05/5 = 0.01 were considered statistically significant.

Details of chronological age (CA), verbal mental age (VMA) across the three groups are presented in Table 6. The Down syndrome group was matched to one group of typically developing boys on chronological age (CA) (TD2) and to one group of typically developing boys on verbal mental age (VMA) (TD1).
Univariate analyses of variance (ANOVA) were performed with GROUP (children with Down syndrome, typically developing boys matched on verbal mental age, and typically developing boys matched on chronological age) as the independent variable and the AGE measures as the dependent variables. The ANOVA analyses revealed a significant GROUP effect for chronological age (CA), \( F(2,33) = 15.102, p < .001 \), and a significant GROUP effect for verbal mental age (VMA), \( F(2,33) = 16.686, p < .001 \). Post-Hoc Scheffe comparison was used to analyze group differences on chronological age (CA) and verbal mental age (VMA).

Chronological Age. A post-hoc Scheffe comparison test revealed no significant difference between the Down Syndrome group and typically developing group matched on chronological age (CA) \( (p = .85; \text{ns}) \), suggesting that the Down Syndrome group was appropriately matched to the typical control group on chronological age (CA). As expected, Scheffe tests revealed a significant difference in chronological age (CA) between the Down syndrome group and the verbal mental age (VMA) matched typically developing control group \( (p < .001) \), indicating that the Down syndrome group was older on average than their mental aged matched counterparts. Similarly, a significant difference in chronological age was found between the typically developing control group matched on chronological age (CA) and the typically developing control group matched on verbal mental age (VMA) \( (p < .001) \), supporting the accurate matching of groups.

Verbal Mental Age. A post-hoc Scheffe comparison test revealed no significant difference in verbal mental age between the Down syndrome group and the typically developing control group matched on verbal mental age (VMA) (TD1) \( (p = .76; \text{ns}) \),
suggested that the Down syndrome group was appropriately matched to this typically developing group on verbal mental age. As expected again, Scheffe tests revealed a significant difference on verbal mental age between the Down syndrome group and chronological age (CA) matched controls (TD2) \((p < .001)\), where boys with Down syndrome had a lower mental age than the chronological age (CA) matched controls. Similarly, a significant difference in verbal mental age was found between the two typically developing groups with the chronological age (CA) matched controls (TD2) scoring significantly higher than the verbal mental age (VMA) matched controls (TD1) \((p < .001)\), suggesting that the control groups were appropriately matched to the Down syndrome group.

Table 6

*Chronological and Verbal Mental Age by Group*

<table>
<thead>
<tr>
<th></th>
<th>Down syndrome Group</th>
<th>VMA Control Group</th>
<th>CA Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>DS</td>
<td>TD1</td>
<td>TD2</td>
</tr>
<tr>
<td>N=12</td>
<td>N=12</td>
<td>N=12</td>
<td></td>
</tr>
<tr>
<td>Chronological Age</td>
<td>Mean (SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>107.58 (14.51)</td>
<td>65.92 (9.8)</td>
<td>102.83 (30.55)</td>
</tr>
<tr>
<td>Verbal Mental Age</td>
<td>Mean (SD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>49.75 (14.81)</td>
<td>58.50 (9.1)</td>
<td>112.58 (46.87)</td>
</tr>
</tbody>
</table>
**Sequential Processing and Counting Task Performance Across Groups**

Given that verbal mental age differed significantly between groups, parametric analyses were used to test post hoc differences in performance on the sequential and counting tasks across groups. Accordingly, verbal mental age (VMA) was used as a covariate in these subsequent group analyses. To examine whether differences existed in sequential processing, performance on the *Treasure task* was compared across the 3 groups. Furthermore, performance was compared across the 3 groups on the *Counting task* to see whether differences existed on this task. Finally, performance of the 3 groups on both tasks was compared together to see if there was an effect of task and group membership on level of performance.

Five Repeated Measures Mixed ANCOVAs were used to examine differences across the groups among the five performance variables from the tasks: NUMBER OF RESPONSES (total number of hits on screen), NUMBER OF FALSE ALARMS (total number of hits minus the target responses), NUMBER OF REPETITIONS (number of immediate repeat responses after hitting a target), NUMBER OF RETURNS (repetitions on a previous target after an intervening response), and MEANTIME (average pointing response time for each target). Separate one-way ANOVAs across the different variables followed by post-hoc Scheffe were used to analyze the main and interaction effects in detail. However, to reduce the likelihood of Type I errors, the Bonferroni correction test was used where only those results meeting an alpha level of 0.05/5 = 0.01 were considered statistically significant.

The analysis revealed only one significant main effect of GROUP on one of the dependent variables, NUMBER OF RETURNS, $F(2, 31) = 27.123$, MSE = .264, $p <$
.001 and one significant interaction effect for GROUP x TASK on the dependent variable, NUMBER OF RETURNS, $F(2, 31) = 24.26$, MSE = .266, $p < .001$. To follow up these analyses one-way ANOVAs with post-hoc Scheffe were computed to look at the main effect of GROUP and the interaction effect of GROUP by TASK independently. As can be seen in Figure 3, these comparisons revealed that there was only a significant difference between groups on NUMBER OF RETURNS on the Treasure Task, $F(2, 35) = 39.365$, MSE = .476, $p < .001$. Moreover, boys with Down syndrome made a greater number of returns on the Treasure Task than both chronological age matched controls ($p < .001$) and verbal mental age matched controls ($p < .001$). However, there was no significant difference between the verbal mental age (VMA) matched controls and the chronological age (CA) matched controls ($p = .491$, ns). Furthermore, this difference in performance was only significant on the Treasure Task whereas boys with Down syndrome were comparable to the verbal mental age (VMA) matched controls ($p = .885$, ns) and to the chronological age (CA) matched controls ($p = .104$, ns) on the Counting Task. However, it is important to note and keep in mind that although there were no significant differences on the counting task, which is in direct contrast to the hypotheses, this can be explained by the fact that the measure we used left the boys with Down syndrome unable to do what was inherent to the task, which is counting out loud. Thus, the boys with Down syndrome were compared to typically developing boys only on pointing performance and not on verbal counting performance. In the end, this means that the boys with Down syndrome faired far worse on the counting task than on the treasure task and were not performing at a level even comparable to their typically matched peers.
Figure 3. Number of Returns

From these analyses it was found that on both the *Treasure Task* and *Counting Task*, measures of sequential processing and counting, respectively, there were no significant differences between any of the 3 groups on NUMBER OF RESPONSES, NUMBER OF FALSE ALARMS, NUMBER OF REPETITIONS, and MEANTIME (Refer to Figures 4, 5, 6, & 7). Thus, the only significant difference between GROUPS and GROUP by TASK was where boys with Down syndrome made errors of RETURN significantly more often than both the verbal mental age (VMA) and chronological age (CA) matched typically developing boys only on the *Treasure Task*. 
Figure 4. Number of Responses
Figure 5: Number of False Alarms
Figure 6. Number of Repetitions
Analyses of Age-related changes

Pearson Product moment correlations were used to examine the relationship between chronological age (CA) and performance on different measures in the Down syndrome, the verbal mental age (VMA) control group and the chronological age (CA) control group.

For the chronological age (CA) matched typically developing control group, positive and high correlations were observed between chronological age and scores on the PPVT-III (measure of verbal mental age ($r = .84, p < .01$)). In addition, a negative and moderate correlation was found on NUMBER OF FALSE ALARMS ($r = .59, p < .05$) and a negative and high correlation on MEAN TIME ($r = .94, p < .01$) on the
Treasure Task. A negative and high correlation was also found for NUMBER OF FALSE ALARMS on the Counting Task ($r = .74, p < .01$). These correlations indicate that this control group follows a typical developmental trajectory of increasing verbal mental age (Refer to Figure 8), less errors, and faster reaction times with chronological age, especially on tasks that tap into basic numerical competencies.

For the verbal mental age (VMA) typically developing control group, there were no significant correlations between any of the measures and chronological age. This finding indicates that as expected our matching technique was successful as these boys were significantly younger and had little variance in both chronological age (CA) and verbal mental age (VMA). It follows then that there would not be a significant difference correlation between age and these measures as they were all performing at the same developmental level expected for their age.

Correlations for the boys with Down syndrome revealed no significant interaction between chronological age (CA) and scores on the PPVT-III (measure of verbal mental age). This suggests that unlike typically developing children, boys with Down syndrome do not follow a normal developmental trajectory on measures of verbal mental age (VMA) (Refer to Figure 6). However, there were two significant correlations between chronological age (CA) and two dependent measures on the Treasure Task. There was a negative and high correlation between chronological age (CA) and both NUMBER RESPONSES ($r = .73, p < .01$) and NUMBER FALSE ALARMS ($r = .71, p < .05$). There were no significant interactions on any of the variables of the Counting Task. These findings are indicative of the fact that boys with Down syndrome are developing typically in terms of basic numerical skills as sequential processing is the
most basic prerequisite for counting but when it comes more advanced concepts that involve counting and cardinal understanding there are no differences because they do not follow a typical developmental trajectory for number skills. This pattern further emphasizes the unique developmental trajectory on tasks of number processing of children with Down syndrome when compared to typically developing children.

Figure 8. Pearson Correlation Between Chronological Age and Verbal Mental Age
CHAPTER V
Discussion

The results from the present study represent a systematic investigation of sequential processing and counting skills among boys with Down syndrome as compared to a group of verbal mental age (VMA) matched control boys (TD1) and a group of chronological age (CA) matched control boys (TD2). In general, the hypotheses put forth were supported, yet this may not be obvious from an initial review of the results. With regard to the sequential processing measure, it was predicted that boys with Down syndrome would perform comparably to both groups of typically developing boys, such that there would be no significant differences between groups on number of errors or reaction time. In terms of the counting measure, it was predicted that differences in performance would emerge, where significant differences would be apparent between boys with Down syndrome and verbal mental age (VMA) matched controls and even greater differences between boys with Down syndrome and chronological age (CA) matched controls. Thus, it was expected that the boys with Down syndrome would present with both increased error rates and increased reaction time on the counting task.

In terms of the first and second hypothesis, children with Down syndrome did perform comparably (reaction time and error rates) to typically developing children matched on both verbal mental age (VMA) and chronological age on the treasure task on all measures except for ‘number of returns’. In respect to hypothesis three and four it was predicted that significant differences would emerge between boys with Down syndrome and verbal mental age (VMA) matched boys and even greater differences
between boys with Down syndrome and chronological age (CA) matched boys. These hypotheses were in fact supported. This can be explained by the fact that the data that was analyzed only comparing pointing performance between the groups, where boys with Down syndrome performed comparably to both groups of typically developing boys. However, boys with Down syndrome had grave difficulty counting out loud in conjunction with the pointing so much so that there was little data to analyze regarding their verbal counting performance. Therefore, it appears that the hypotheses were supported as boys with Down syndrome performed significantly worse on the counting task than on the treasure task and that although comparable to their typically developing matched controls on the treasure task they were not comparable on the counting task.

*Typical Development of Numerical Cognition*

Research on typically developing children indicates that an essential characteristic of human cognition is the ability to produce and learn sequential actions (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003), which gradually develops over childhood and adolescence (Cherkes-Julkowski, Sharp, & Stolzenberg, 1997). Sequential processing, which relies on the ability to follow a sequence of steps to reach a goal, is the most basic prerequisite for counting. Thus, sequential processing is developmentally prior to counting, which itself, frequently precedes a maturing sense of cardinal knowledge (Bermejo, 1996). Scerif et al. (2004) suggest that as children age they demonstrate an increasing ability to search for targets among distracters. In their investigation, Scerif et al. (2004) highlight that the response paths of older children were characterized by a greater number of successful discriminations of targets from distracter stimuli and by children's inhibition of their previous responses. With respect
Counting children are required to sequence across visual-spatial positions by applying an accurate one-to-one mapping between space and number to elicit reliable counting behaviour. Difficulty in carrying out a sequence of behaviours is negatively related to counting ability, as is difficulty in changing strategies to reach a goal (Bull & Scerif, 2001). Therefore, in order for the development of precise counting behaviour and cardinal understanding to emerge, sequential processing must initially be established.

Differences Between Groups on the Sequential Processing Task and Counting Task

Overall, the three groups did in fact perform comparably on most of the performance variables on both experimental measures: the Treasure Task and the Counting Task. Where differences emerged they were related to error types and as such these findings offer some novel insights to the development of sequential processing and counting in children with Down syndrome.

Treasure Task. In the present study, the sequential processing measure required the child to follow a series of steps to reach a goal (treasure chest). At first glance, it appears that the children with Down syndrome were comparable to the typically developing control boys on this task. However, closer inspection reveals that the Down syndrome group made significantly more ‘number of return’ errors than both control groups. This type of error involves returning to a previously hit target after subsequent targets have already been hit. This type of error could be due to weak short-term memory or attentional difficulties as children may forget which targets have already been hit or they may become distracted and thus not stay focused long enough to remember which parts of the task have already been completed. This type of error can be distinguished from both errors of perseveration and hitting distracter items. Errors of
perseveration are characterized by a lack of inhibitory control or deficient attentional skills whereas hitting distracters are due to inefficient visuo-construction or executive planning skills. In the present study, the tendency to perseverate on the treasure task would be marked by significantly poorer performance on ‘number of repetitions’, whereby the child would immediately and continually point to an already marked target before moving onto the following target. Furthermore, visuo-constructive errors would be marked by an increase of total ‘number of false alarms’. However, boys with Down syndrome did not significantly differ on either of these measures in comparison to typically developing controls.

**Counting Task.** In the current study, the counting measure required each child to point to and count the number of targets on the screen and to provide a cardinal response. On this task, the results revealed that there were no significant differences between groups on any of the performance variables: ‘number of responses’, ‘number of false alarms’, ‘number of repetitions’, ‘number of returns’, and ‘mean time’. The fact that there were no apparent differences between the groups on this measure is noteworthy for two reasons. First of all, this task goes beyond the aforementioned sequencing task because it not only requires the child to follow a series of steps but also entails the ability to count aloud in conjunction with this behaviour. Thus, it would seem surprising that the observed decline in performance of boys with Down syndrome on ‘number of returns’ in the sequencing task would not necessitate the same type of performance discrepancy between groups on the counting task. Second, one would predict that significant differences should emerge between groups, such that boys with Down syndrome would not only display poorer performance on ‘number of returns’ but
that this would generalize to 'number of false alarms', 'number of repetitions', and 'mean time'. This increasing discrepancy between groups would subsequently be explained by the greater demands placed on the children where they are now required to count out loud, while attributing meaning to each subsequent step. Our results are actually consistent with this hypothesis, albeit this is not obvious from the outset. The current analyses revealed no significant differences between the groups because the boys with Down syndrome had such grave difficulty with the counting task that they were not counting out loud. The boys with Down syndrome were unable to coordinate both the behaviours necessary for successful counting. Hence, for boys with Down syndrome the counting task became a measure of purely sequential processing and it follows that their pointing performance would be facilitated.

Comparing Performance on the Sequential Processing Task and Counting Task

During the sequential task, groups did not demonstrate differences in performance other than an increase in 'returns' for boys with Down syndrome. This similarity in performance could be due to their strength in visuo-spatial cognition (Wang & Bellugi, 1994; Jarrold & Baddeley, 2001), which may play a role in numerical competence (Ansari et al., 2003). These results suggest that boys with Down syndrome may have equivalent rates of cognitive ordering and developing comparably to typically developing boys when they are required only to sequentially process a series of basic steps.

However, during the counting task, differences materialized when children were required to sequentially process information while attributing meaning to each subsequent step. Thus, developmental differences emerge in sequential processing when
these children are required to apply meaning to the information they are receiving, such as in the current study when children were asked to count a number of targets and provide an accurate cardinal response. This finding provides support for the notion that sequential processing demonstrates a developmental primacy over counting (Trick & Pylyshyn, 1994). Therefore, while boys with Down syndrome are performing comparably to typically developing boys matched on verbal mental age (VMA) and chronological age (CA) on sequential processing, they are well behind in their development of subsequent counting skills and cardinal understanding.

**Atypical Developmental Trajectories and Syndrome Specific 'Signatures'**

Identifying the distinct or unique ‘signatures’ that distinguishes developmental disorders from each other and from typically developing children has become a huge focus of research in recent years. There is now a growing consensus that so-called ‘commonalities’ in behavioural or global cognitive delay does not infer common cognitive mechanisms or pathways. The present findings suggest that boys with Down syndrome have a core difficulty in working memory (Jarrold & Baddeley, 2001; Jarrold, Baddeley, & Phillips, 2002; Jarrold et al., 2004) such that they revert back to previously marked targets because they may not remember which ones they have already hit; the number of steps to reach a goal may have placed a heavy demand on their working memory. Hence, the significant short term and working memory deficits reported among children with Down syndrome may well contribute to understanding their unique profile of numerical deficits.

This type of error displayed by children with Down syndrome is distinct from errors commonly shown by boys with Fragile X syndrome, who present with a primary
difficulty of inhibiting responses and thus tend to perform errors of perseveration. This would suggest that they would have an increased tendency to make errors of 'repetition' on our tasks. Previous research has demonstrated that children with Fragile X syndrome have acute problems in moving on from one response to another when searching a visual display (Munir, Wilding, & Cornish, 2000b; Belser & Sudhalter, 2001; Wilding et al., 2002; Scerif et al., 2004). It may be possible that boys with Down syndrome are better able to switch to more adaptive strategies and effectively alternate responses to items presented in sequence. Thus, it seems highly probable that this impairment in sequential processing will lead to even greater difficulties in learning basic counting skills than in children with Down syndrome.

The aforementioned errors can be further contrasted to those in Williams syndrome, who present with visuo-constructive and executive planning deficits (Ansari et al., 2003; Scerif et al., 2004; Paterson, 2006). They tend to hit distracter items more frequently and would be more likely to show poorer performance on 'number of false alarms' on our tasks. However, the findings from a recent study indicate that in children with Williams syndrome, the understanding of the cardinality principle, although delayed, is guided by their relative strength in verbal ability compared to typically developing children (Ansari et al., 2003). Thus, children with William syndrome may have less difficulty with these tasks that tap into early counting skills.

In addition, the problems with inattention prevalent in children with both Down syndrome (Carr, 1998; Coe et al., 1999; Clark & Wilson, 2003; Wilding et al, 2002) and Fragile X syndrome (Turk, 1998; Wilding et al, 2002) may be crucial in understanding their unique numerical deficits. A series of recent studies by Munir et al. (2000a, b) on
attention functioning in typically developing children drew the conclusion that children with poor attention processing have a weakness in central executive function, which impairs their ability to handle problems requiring some form of complex rule changes to achieve successful responses. Thus, it is conceivable that the core deficits in attention, which characterize both individuals with Down syndrome and Fragile X syndrome may contribute to their overall poorer performance on numerical tasks.

When studying atypical populations it is not sufficient to state that a group performed unsuccessfully on a given task. Rather, it is imperative to understand the many factors, other than overall cognitive delay, that may contribute to failure and are unique to the syndrome itself. In some cases, deficits in a number of areas (e.g., attention, inhibition, language) can account for failure on any particular task. In children with Down syndrome, language impairments, receptive vocabulary deficits, or memory deficits may have contributed to their overall poorer performance. Take for example, Caycho et al. (1991) who found that weaknesses in language deficits accounted for poor performance in the counting behaviour of children with Down syndrome. Given the poor receptive language of children with Down Syndrome and its relationship to numerical skills (Abbeduto et al, 2003; Abbeduto et al., 2001; Laws, Byrne, & Buckley, 2000; Nye, Cibbens, & Bird, 1995) it is possible that tasks which demand strong receptive language skills may have been particularly difficult for participants with Down syndrome to comprehend and therefore accomplish successfully. In addition, Ansari et al. (2003) found that among their tasks assessing numerical conception, visuo-spatial competence accounted for success among typically developing children, whereas greater verbal ability contributed to a higher success rate among children with William’s
Counting 49 syndrome. It may be then that in atypical populations, such as Down syndrome, verbal rather than visuo-spatial skills are responsible for numerical competencies. Thus, it is possible that the language component, inherent to most math tasks could be impacting upon the numerical performance of boys with Down syndrome, rather than visuo-spatial skills.

The findings from the present study are significant from a developmental perspective, which is imperative when comparing typical and atypical populations; it can demonstrate the importance of developmental timing in the trajectory of cognitive skills, such as numeracy, and its central role in development. The current findings fit into a neuroconstructivist model, such as that presented by Karmiloff-Smith. This perspective recognizes the interactive role across many systems: from the genetic to the neurological systems to the cognitive and the affective systems and then to the behavioural and environmental systems (Karmiloff-Smith, 1998). From this approach, the additional chromosome in children with Down syndrome will be expected to subtly change the course of development, with stronger effects on some outcomes than others (Karmiloff-Smith, 1998). Thus, it is argued that development itself plays a crucial role in phenotypical outcomes and that in atypical populations, such as Down syndrome, this involves a complex and dynamic interplay between various factors that together will more accurately explain poor versus successful performance and will lead to different end states.

Limitations

There are a number of limitations within the present study that need to be addressed in future research designs. First, the relatively small sample size of the Down
syndrome group (N=12) limits the interpretations of the findings and their applicability to a wider range of children. However, the current study is part of a larger project, which will validate findings among a greater sample of children with Down syndrome over the next two years. Second, given that the present study incorporated novel, experimental paradigms to assess sequential processing and counting, an additional standardized measure of numerical cognition would have complemented the battery. However, few numerical tasks have been standardized for children with mental retardation. Third, the absence of a visual-spatial battery meant the we could not evaluate the relationship between visual-spatial functioning and numerical processing, two factors that have been shown to be highly correlated in typically developing children (Ansari et al, 2003) and is a particular strength for children with Down syndrome (Wishart & Duffy, 1990; Wang & Bellugi, 1994; Jarrold & Baddeley, 2001). Fifth, the lack of significant differences found between the boys with Down syndrome and typically developing boys could in fact have been related to the measures used. The results may have been different if more or different measures tapping into numerical skills were utilized. The utilization of a greater number of diverse numerical tasks would be useful in future research in this area. Finally, given their relatively poor receptive skills, children with Down syndrome may have had some difficulties in understanding the task instructions. However, it is important to note that they were given the instructions both verbally and visually and they did perform comparably to typically developing children, which indicates that they did understand the instructions given to them. Finally, no information was obtained regarding the different methods of instruction received by the boys with Down syndrome prior to being assessed. It would have been useful to know the possible
impact of types of instruction on the development of numerical skills in children with Down syndrome.

Future Directions

The present study was not specifically designed to assess for between group differences in the developmental trajectory. However, this study is part of a larger study that in future will be investigating the development of these numerical skills once a year over a period of 3 years. In addition, the study will compare the performance of these boys with Down syndrome to boys with Fragile X syndrome. This approach is important in revealing the detailed processes involved in demonstrating such a skill and to understand whether differences are specific to a syndrome or associated with mental development in general.

Future studies would benefit from incorporating a cross-syndrome perspective to examine cognitive functioning and within cognitive domains. For example, comparing performance across different aspects of numerical cognition in Down syndrome, Williams syndrome, and Fragile X syndrome would provide important information about syndrome-specific similarities and differences. This information would help clinicians and educators to target interventions and resources that recognize the unique syndrome ‘ signatures’. Using a cross-syndrome design and situating it within a developmental framework would further advance our understanding of ‘ signatures’ change with developmental time.

Future research should also emphasize the underlying processes that may impact upon successful learning. For example, assessing children with Down syndrome on mathematics tasks that tap into specific measures of working memory, visuo-spatial
cognition, and receptive language would provide a better understanding about the origin of their deficits. If researchers are able to isolate more specifically the age of onset of a particular deficit, perhaps intervention could be targeted during critical periods and help lessen the impact of the deficit on numerical performance.

Finally, since children with Down syndrome have been shown to have a relative weakness in receptive language, verbal mental age (VMA) alone may be insufficient to detect fair comparisons between the Down syndrome group and typically developing groups. For example, Wishart and Duffy (1990) show that for young children with Down syndrome, overall delay in general cognitive scores masks an uneven pattern of performance with visuo-spatial skills exceeding scores in the verbal domain. Thus, children with Down syndrome may not fair as well when the measure of mental age (MA) is based on receptive vocabulary alone. As a result, future studies may seek to compare children matched separately on verbal and non-verbal mental age to control for this.

I *mplications for School Psychology*

It is imperative to tease apart cognitive domains and thereby identify crucial strengths and weaknesses that address syndrome-specific 'signatures'. This approach is crucial in relaying effective strategies to school practitioners who want to support a rewarding and successful educational experience for these children. This is where the findings from the current study prove to be vital. The data gathered from the current study can be used to tailor instructional techniques to the unique needs of students with Down syndrome and in turn facilitate their learning experience.
Fundamental to this research is the identification of how impairments, such as we have identified, will affect the child with Down syndrome in their ability to succeed and to respond to the many demands of the educational environment. For example, since auditory memory is a weakness (Marcell et al., 1988; Marcell & Weeks, 1988; Hulme & Mackenzie, 1992) and visuo-spatial skill are a strong point in children with Down syndrome (Wishart & Duffy, 1990; Wang & Bellugi, 1994; Jarrold & Baddeley, 2001), educators can take the necessary steps to ensure all instruction includes visual as well as auditory input. Children with Down syndrome can benefit from strategies that include visual feedback while learning to count because of their strength in visual attention. Also, having them do assignments on the computer or giving them instructions on the computer could be helpful. Similarly, to compensate for their weakness in receptive language, math vocabulary words can be introduced and taught at the outset of each lesson so that the child with Down syndrome can better benefit from math instruction. Hence, in these two situations, an educator should implement reasonable accommodations that utilize the child’s strengths and circumvents their weaknesses.

Overall, the atypical pattern of performance for the boys with Down syndrome emphasizes that these children need to be provided with syndrome-specific educational strategies early in development in order to maximize their potential. As mentioned previously, Faragher & Brown (2005) emphasize that numerical preparation must begin early in childhood and continue in school as it is related to quality of life in individuals with Down syndrome. Moreover, Rynders et al. (1997) argue that misinformation and lack of information about the educational potential of school children with Down
syndrome have lead to educators, psychologists, and other school personnel forming low educational expectations of these children.

The utilization of specific psycho-educational support services that have an empirical basis is crucial. Assessment of these children must be multidisciplinary, multimodal, and involve a variety of assessment techniques. Evaluation of these children should go beyond psychological testing alone and include an integration of review of reports and records, interviews with significant caregivers, and observations of the child in a variety of settings. This systemic approach will contribute significantly to understanding the severity and pervasiveness of a given problem over time.

The findings from the present study are an integral addition to the emerging profile of cognitive deficits and syndrome-specific 'signatures' in children with Down syndrome. First, they provide evidence that the performance of children with Down syndrome on basic sequential processing tasks is comparable to that of both verbal mental age (VMA) and chronological age (CA) matched controls. Second, when the task requires more advanced numerical processing, which requires the ability to sequentially process a series of steps while attributing meaning to each one, our findings indicate that boys with Down syndrome are developing well behind their typical matched controls. The boys with Down syndrome do not appear to yet have a fully mature counting system or an understanding of the principle of cardinality. They may well follow the same trajectory of numerical development as typically developing children but at a slower pace. Thus their developmental pathway could be viewed as delayed rather than deviant.
In the end, our main priority is to disseminate our findings broadly to include researchers, parents, and school personnel alike. We stress the need to tease apart cognitive domains to look for syndrome-specific 'signatures', which will contribute to the design of appropriate and timely education strategies that serve to maximize the potential of children with Down syndrome.
References


Journal of Autism and Developmental Disorders, 29, 149-56.


Appendix B

Learning to Count and Sequential Responding in Children with Fragile X Syndrome, Down Syndrome and Typically Developing Children

Dear Sir, Madame

Introduction

You have kindly agreed for us to contact you so that we can give you more information about our study. We are currently conducting a research project looking at early counting skills and sequential responding in typically developing boys. We are contacting you now because we would like to provide you with information about this project and ask you to consider participating in our study. The information included below reviews the purpose of the study and what will be required of you if you do decide to participate. Please take the time to read this information and feel free to discuss it with anyone from our research team. You will be given as much time as you need in order to make a decision about whether or not you would like to participate.

What is the purpose of the study?

The focus of this research project will be on identifying the proficiencies and deficiencies in one aspect of cognition that is undoubtedly a crucial component of a child's learning experience - the development of basic numerical skills. The ability to count and to use counting to determine exact quantities is seen as a fundamental numerical ability that typically developing children acquire by the age of approximately 5 years. Only when children understand why they need to count (the cardinality principle) can they be said to have a concept of the meaning of counting and number. This knowledge will form the building blocks for further numerical development and achievement.

The objectives of our research are twofold. First, we wish to document the development of numerical competence among typically developing boys through the ages of 5 to 11 years. Secondly, the information provided by these initial findings will help to understand the development of numerical abilities in children with two genetic disorders (Fragile X syndrome and Down syndrome). As a result, we will provide information concerning the developmental progression of numerical abilities in typically developing children and for the creation of syndrome-specific educational programs and curriculum.

What are the educational implications of our projects?

Our project will provide teachers with specific information regarding the unique needs of the "coded" children in their classrooms, alongside relevant details outlining the general development of numerical skills. The syndrome specific information, however, can only be acquired by contrasting the performance of typically developing children with that of the performance of children with intellectual disabilities. As such, we are presently looking for 40 typically developing boys between the ages of 5 through 11.
The integration of special needs children into typical classrooms has reflected a lack of resources and support for educators who must cope with the new demands accompanying this radical shift in our educational climate. Therefore, it is vital that educators receive information that highlights the unique needs of their individual students and provides effective recommendations for successful classroom integration. This kind of targeted intervention will undoubtedly serve to increase instructional efficiency, which will positively impact the educational experience of children with developmental disabilities and typically developing children. Finally, educators will benefit from these interventions by having to spend less time and energy incorporating the reality of special needs into the already demanding task of creating lesson plans that must take into account the diversity found among typically developing children. We can no longer assume that educators will find the time to gather the information they so desperately require in order to cope with the realities of integration - they need the support and guidance that only this kind of research can provide.

Who is organizing this study?

This is a collaborative research project supervised by Dr. Kim Cornish (Associate Professor, Canada Research Chair in Neuropsychology Education), Dr. Jake Burack (Full Professor) of the Department of Educational and Counselling Psychology at McGill University, and Natalie Waxman (M.A. Candidate, McGill University). Drs’ Cornish and Burack’s area of expertise is the study of the cognitive and behavioural functioning of typically developing children and children with developmental disorders such as fragile X syndrome, Down syndrome, and autism.

What will each child be required to do?

Individual children will be assessed during one visit to your school for approximately one hour and twenty minutes. Testing schedules will be organized in consultation with school principals and teachers.

Testing session:

1) Each child will be assessed for nonverbal ability with the Leiter International Performance Scale-Revised, during which the child is required to complete several reasoning and visual-spatial tasks.

   → This task will take about 25 minutes to administer.

2) Each child will be assessed for number processing skills. Each child will be seated comfortably in front of a computer monitor and will be asked to respond to a single target. A variety of stimuli will be employed, which include miniature aliens, blocks, and numbers. The child responds by pressing a button on a touch-pad, with respect to either the size or location of the target.

   → These tasks will take about 35 minutes to administer.
3) Each child will be assessed for verbal ability with the Peabody Picture Vocabulary Test (PPVT). The child will be shown a series of four black and white illustrations and will be asked to select the one picture that best represents the meaning of a word that has been orally presented by the examiner.

→ This task will take about 15 minutes to administer.

4) Each child will be assessed for basic sequential and counting skills. Each child will be seated comfortably in front of a computer monitor and respond to visual stimuli that will be presented. A variety of stimuli, such as circles and animated symbols, are presented on the screen. The tasks involve a judgment by your child about the stimuli and require a response using touch-screen technology.

→ These tasks will take approximately 20 minutes to administer.

Assessments will be punctuated with as many breaks as required by each child.

What will happen to the information provided by the child?

The child will be assigned a file number, and all materials collected regarding that child will be labelled with only the case number. A list of the participant’s names with their assigned file numbers will be kept separately from the materials collected and stored in a locked cabinet at our research facilities on the McGill University campus. Moreover, this unidentifiable data may be included in future academic presentations and publications that will be made available to parents and educators, upon request.

Are there any risks to participating?

There are no physical or psychological risks inherent in this study. The tasks are simple and will likely be enjoyable for the participants.

Withdrawal from the study

Parents can withdraw their children from this study at any time. The refusal to participate in the study will not affect their classroom experience in any way. Moreover, the child will be given the choice to discontinue with the tasks at any time for any reason.

Will participants benefit in any way from the study?

General results of this study (no specific results concerning your child) will be available to the child’s school along with specific information about the strengths and weakness in numerical ability among typically developing boys across grade levels- an area often neglected by researchers who tend to only examine female performance. This invaluable source of information will facilitate the planning of education programs that target the specific needs of these students early on in development in order to maximize academic potential.
INFORMATION AND CONSENT FORM

<table>
<thead>
<tr>
<th>Institution:</th>
<th>Faculty of Education, McGill University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title of Project:</td>
<td>Learning to count and sequential responding in children with Fragile X syndrome, Down syndrome and typically developing children</td>
</tr>
<tr>
<td>Project leader:</td>
<td>Kim Cornish, Ph.D.</td>
</tr>
<tr>
<td>Other Investigators:</td>
<td>Natalie Waxman, BA.</td>
</tr>
</tbody>
</table>

Dear Parent or Guardian,

Your school has kindly agreed to participate in this study. We are currently conducting a research project looking at early counting skills in typically developing boys. We are contacting you now because we would like to provide you with information about this project and ask you to consider allowing your child to participate in our study. Please take the time to read this information and feel free to discuss it with anyone from our research team.

What is the purpose of this study?

The focus of this research project will be on identifying the proficiencies and deficiencies in one aspect of cognition that is undoubtedly a crucial component of a child's learning experience - the development of basic numerical skills. The ability to count and to use counting to determine exact quantities is seen as a fundamental numerical ability that typically developing children acquire by the age of approximately 5 years. Only when children understand why they need to count (the cardinality principle) can they be said to have a concept associated with the meaning of counting and number. This knowledge will form the building blocks for further numerical development and achievement.

The objectives of our research are twofold. First, we wish to document the development of numerical competence among typically developing boys through the ages of 4 to 11 years. Secondly, the information provided by these initial findings will help to understand the development of numerical abilities in children with two genetic disorders (Fragile X syndrome and Down syndrome). As a result, we will provide information concerning the developmental progression of numerical abilities and for the creation of syndrome-specific educational programs and curriculum. This type of information will provide us with a tool for the development of effective strategies to improve educational programs for children affected by such syndromes.
**Procedure:**

We are asking if you would like to participate in this study. If you agree, then you will be assessed as soon as is convenient for you. Each child will be assessed during one visit to their school for approximately one hour and twenty minutes.

**Testing session:**

1) Each child will be assessed for nonverbal ability with the Leiter International Performance Scale-Revised, during which the child is required to complete several reasoning and visual-spatial tasks.

⇒ This task will take about 25 minutes to administer.

2) Each child will be assessed for number processing skills. Each child will be seated comfortably in front of a computer monitor and will be asked to respond to a single target. A variety of stimuli will be employed, which include miniature aliens, blocks, and numbers. The child responds by pressing a button on a touch-pad, with respect to either the size or location of the target.

⇒ These tasks will take about 35 minutes to administer.

3) Each child will be assessed for verbal ability with the Peabody Picture Vocabulary Test (PPVT). The child will be shown a series of four black and white illustrations and will be asked to select the one picture that best represents the meaning of a word that has been orally presented by the examiner.

⇒ This task will take about 10 minutes to administer.

4) Each child will be assessed for basic sequential skills. Each child will be seated comfortably in front of a computer monitor and respond to visual stimuli that will be presented. A variety of stimuli, such as circles and animated symbols, are presented on the screen. The tasks involve a judgment by your child about the stimuli and require a response using touch-screen technology.

⇒ This procedure will take approximately 10 minutes to administer.

All assessments will be punctuated with as many breaks as your child needs.

**Advantages of the proposed studies:**

We will assess your child's level of cognitive functioning (test of information processing). We will provide the results of these investigations to you and, upon your request, to your physician. There is no specific benefit in participating in the study and we will not be providing individual results since this is a research study. Your participation, however, will contribute to our initiative to document the developmental
progression of numerical abilities in typically developing children. We will also be using this information to increase our understanding of numerical processing in Fragile-X syndrome and Down’s syndrome, which may help in the treatment of these conditions.

Disadvantages of the proposed studies:

There are no known side effects associated with participating in the psychological and numerical testing.

Confidentiality:

The results of all your tests will remain strictly confidential, and will only be known to the investigators and to the people carrying out the studies. The results will be published for the overall group, but you will not be specifically identified.

Participation:

Participation is voluntary. You may refuse to participate or withdraw from the study at any time. The refusal to participate in the study will not affect their classroom experience in any way. Moreover, your child will be given the choice to discontinue with the activities at any time for any reason.

Incidental Findings:

The cognitive findings will be communicated to you and, upon your request, to your physician, as indicated above.

I want my child to participate, what do I do next?

This information sheet is for you to keep. Also included is a consent form that you will have to sign to indicate to us that you have willingly allowed your child to participate in our study. As soon as possible, return the signed consent form to your child and instruct them to forward it to their homeroom teacher.
Declaration of the parent:

In signing this consent form, I recognize that all aspects of the study have been explained to me, and that I understand the study. I also agree that I have had the opportunity to ask questions about the study, and that all my questions have been answered satisfactorily.

I, __________________________, have read the above description with one of the investigators, __________________________. I fully understand the procedures, advantages and disadvantages of the study, which have been explained to me. I freely and voluntarily consent to participate in this study.

______________________________
Name of participant

______________________________
Signature of parent

______________________________
Date

______________________________
Date of birth of participant

______________________________
Name of witness

______________________________
Signature of witness

______________________________
Date

______________________________
Name of investigator

______________________________
Signature of investigator

______________________________
Date
This consent form clearly specifies the purpose, procedures and conditions required for your child’s participation in the study on “Learning to Count and Sequential Processing in Boys with Down Syndrome”.

1. **Purpose**

   I have been informed that the purpose of this research is to provide answers to important questions about the development of abilities such as the early development of basic number and counting skills, which are a crucial component of a child's learning experience. I understand that the aim of the study is to obtain data to build a reliable developmental trajectory of numerical abilities in boys with Down syndrome as they emerge. This will facilitate in the creation of syndrome-specific educational programs and curriculum.

2. **Procedures**

   I understand that my child will be asked to participate in tasks that involve pointing to pictures, pushing keys on a key board, and playing games. I have been informed that the tasks present no known risk and have been used before with persons of the same age as my child. Everything my child is asked to do will be explained to him beforehand. If my child wishes to stop or not perform the task, he may do so at any point. I understand that my child's performance in the study will not affect his status in any way.

3. **Conditions of Participation**

   I understand that the tasks will be presented in the context of games, and my child and I will receive compensation regardless of performance on the games played. I understand the purpose of this study and know the benefits and inconvenience that this research project entails. I understand that my child’s identity will remain anonymous and all information will
be kept confidential. I understand that all data will be stored in a locked cabinet. I understand that any specific information collected in this study is confidential and is protected under the Freedom of Information and Protection of Privacy Act 1989 (Bill 49).

I have been advised that the data will be used for research purposes only. I consent to the published reporting of this study so long as the results are reported as group averages and my child's name or any other personal information is never used in these reports.

I understand that the researchers involved will be available to answer any questions regarding the procedures of this study.

***********************************************************************
*I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND MY PARTICIPATION IN THIS AGREEMENT. I VOLUNTARILY AGREE AND FREELY CONSENT FOR MY CHILD TO PARTICIPATE IN THIS STUDY.*

_____________________________   ________________________________
Child's Name                   Child's date of birth

_____________________________   ________________________________
Date                           Signature of Parent or Guardian
Appendix C

Verbal Assent for Children Under the Age of 14 Years

Part I - To be read to the child by the researcher:

I am a university student studying to be a school psychologist. As part of my program, I am doing a research project that will help teachers and parents better understand the ways children prefer to learn.

Today, I will be asking you to do a couple of activities with me that involve you writing and reading some numbers and answering some mathematics questions. There are no "right" or "wrong" answers, your responses only help me understand how you prefer to learn. Altogether, these activities will take 50 minutes.

Your parents have given me permission for you to participate in this research project. However, you do not have to participate if you do not want to. If you do want to participate you will not have to answer any questions that you do not want to, and we can stop at any time and I will bring you back to your classroom.

Your responses on these tasks are confidential. That means that only myself and other researchers working with me on this project will see your answers. The results of this research may be published or presented, but your name will not be used and no one will know that you participated in this study.

Do you have any questions?

Do you agree to participate?

Part II - To be completed by the researcher:

I read this form to ................................ and acknowledge that he gave verbal assent to participate.

Signature........................................... Date.............................................