Mental rotation abilities in individuals with Down syndrome – a pilot study

Claire Hinnell¹ and Naznin Virji-Babul²

¹ University of Victoria, Victoria, B.C.
² The Down Syndrome Research Foundation, Vancouver BC, and Department of Psychology, University of Victoria, Victoria, B.C.

Abstract – This pilot study was designed to examine mental rotation ability in individuals with Down syndrome. 7 individuals with Down syndrome (mean mental age = 8.18 +/- 2.73 years; mean chronological age = 29.8 +/- 5.4 years) and a group of 9 typically developing children, matched for mental age, (mean mental age = 8.40 +/- 1.73 years; mean chronological age = 7.2 +/- 1.2 years) were given a version of Cooper and Shepherd’s (1973) mental rotation paradigm. On each trial, participants viewed a symbol representing an upper case ‘F’ or a mirror image of an ‘F’. The symbol was presented at one of eight different orientations. The participant’s task was to determine whether the letter was reversed or non-reversed. Interestingly, both groups showed similar trends in increased reaction times with increasing angular disparity, suggesting that both groups were performing mental rotations. There was no significant difference in reaction time between the typically developing and Down syndrome groups, however, the Down syndrome group made significantly more errors than the typically developing group. Participants with Down syndrome were able to carry out the mental rotations at well above chance level and mental rotation ability was shown to correlate with mental age.

Keywords: Down syndrome, mental rotation

Introduction

Down syndrome is the most frequently occurring chromosomal abnormality, resulting from the presence of an extra partial or complete 21st chromosome. This relatively small increase in genetic material disrupts all aspects of an individual’s physical, mental and social development with cognitive development posing particular challenges. Intellectual disability is present in Down syndrome but the extent of the impairment is quite variable, ranging from mild impairments to severe mental retardation. The specific manner in which the chromosomal disorder influences cerebral development and the resulting intellectual and information-processing deficits is not well understood.

Hartley (1986) and Pipe (1988), drawing from their work on dichotic listening paradigms, proposed that the difficulties in information processing may be attributed to a reversed pattern of cerebral specialization. That is, individuals with Down syndrome may be using the less optimal right hemisphere for processing speech and language. However, Elliott, Weeks and Gray (1990) and Elliott and Weeks (1990) have shown that adults with Down syndrome have greater difficulty with tasks that involve both speech perception and movement organization. They suggest that individuals with Down syndrome have atypical right hemisphere specialization for speech perception and typical left hemisphere specialization for motor control. This separation of systems that are normally controlled by the same left hemisphere may be the underlying basis for the information processing difficulties typically seen in Down syndrome (Elliott & Weeks, 1993).

A standard method for evaluating the ability to perform spatial transformations is through the use of mental rotation tasks originally described by Shepard and Metzler (1971). In their task, Shepard and Metzler showed pairs of line drawings of shapes and asked subjects whether the shapes were identical or a mirror image of the original. The figures were presented in different orientations. Interestingly, the response times increased as the angle from vertical increased. These behavioural data have been replicated and reported by many investigators (Kosslyn, 1980; Shepard & Cooper, 1982;). However, the neural mechanisms underlying this behaviour remain unclear. While there is some speculation that mental rotation is sub served by right hemisphere processing (Deutsch, Bourbon, Papanicolaou & Eisenberg, 1988), there is more recent evidence from
imaging studies to indicate that there is bilateral activation of the hemispheres and that there appears to be a great deal of variability across subjects and no clear hemispheric asymmetries (Cohen et al, 1996).

There are very few studies investigating the problem solving abilities of individuals with Down syndrome using mental rotation tasks. Uecker, Obritz and Nadel (1994) compared the mental rotation abilities of children with Down syndrome (Mean CA = 8 years, 4 months, Mean MA = 3 years, 1 month), learning disabled children (Mean CA = 10 years, 3 months, Mean MA = 7 years, 5 months) and a group of typically developing elementary school children (Mean CA=9 years, 2 months, Mean MA = 11 years, 2 months). They were most closely matched for chronological age but not for mental age. The stimulus used was a stick figure holding a ball in either the right or left hand. The stick figure was rotated from 0 to 360 degrees and the children were asked to determine on which the side the stimulus figure was holding the ball. Both the control and learning disabled children showed a characteristic linear relationship between angular disparity and reaction times. The children with Down syndrome did not show this characteristic relationship. Uecker et al concluded that, since the Down syndrome group performed at low levels, this was indicative of difficulties with spatial transformations.

There are however a number of limitations to this study that make this conclusion debatable. First, the average mental age of the children with Down syndrome, as assessed by the Peabody Picture Vocabulary Test -Revised (PPVT-R; Dunn & Dunn, 1997), was 3 years, 1 month (SD = 1.1) while the mean mental age of the typically developing controls was 11 years 2 months (SD = 2.3). This rather large discrepancy in mental age limits any meaningful comparisons between the two groups. In addition, Marmor (1975) has reported that imagery representing movement first emerges at about the age of 5 years. She demonstrated that the reaction times of 5 year old children showed the characteristic linear relationship with angular disparity when asked to visually rotate panda bear-like shapes differing in orientations. Given that the mean mental age of the children with Down syndrome in Uecker et al’s (1994) study was much less than 5 years, it is not surprising that they were unable to perform the task.

Furthermore, with respect to training, all groups in Uecker et al (1994) appeared to have been given the same number of pretraining trials and instructions. Given the large discrepancy in mental age it is highly likely that the Down syndrome group may not have had appropriate or adequate instruction in how to perform the task.

The present study arose out of an interest to address the question of whether individuals with Down syndrome with a mental age greater than 5 years have the ability to perform spatial transformations.

Materials and methods

Participants

The Down syndrome group consisted of 7 participants who were recruited through the Down syndrome organization in Victoria, British Columbia. Mean mental age (PPVT-III) was 8.18 years (SD = 2.73). The mental age matched group consisted of 9 typically developing children recruited through faculty members in the School of Physical Education at the University of Victoria, British Columbia. Mean mental age as assessed by the Peabody Picture Vocabulary Test -Third Edition (PPVT-III) was 8.40 years (SD = 1.73). Handedness was assessed by the modified Edinburgh Handedness Inventory (Oldfield, 1971). See Table 1 for participant characteristics.

Materials

The experimental apparatus consisted of a computer and keyboard with specific keys colour-coded for various tasks. Individuals were tested either in a laboratory setting at the University of Victoria or in their homes. As a result both laptops and desktop computers were used; the screen size and resolution therefore varied slightly. The computer screen was parallel to the participant’s frontal plane and at eye level. Reaction times were measured by computer from stimulus onset to the pressing of a key by the participant and were recorded in milliseconds.

‘F’ mental rotation test

A version of Cooper and Shepard’s (1973) mental rotation paradigm using an upper case ‘F’ was used in the current study. The symbol was presented as either a letter ‘F’ or as a mirror image (Figure 1). The participant saw either a non-reversed or reversed stimulus on the screen at one of 8 possible orientations relative to the vertical plane (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°).

Table 1. Participant characteristics including mental age (PPVT-III), chronological age, gender and handedness.

<table>
<thead>
<tr>
<th>Down Syndrome</th>
<th>Typically Developing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Age Mean</td>
<td>8.18</td>
</tr>
<tr>
<td>SD</td>
<td>2.73</td>
</tr>
<tr>
<td>Range</td>
<td>(5-12.3)</td>
</tr>
<tr>
<td>Chronological Age Mean</td>
<td>29.8</td>
</tr>
<tr>
<td>SD</td>
<td>5.4</td>
</tr>
<tr>
<td>Range</td>
<td>(22-36)</td>
</tr>
<tr>
<td>Gender</td>
<td>4F, 3M</td>
</tr>
<tr>
<td>Handedness</td>
<td>5R, 1L, 1M</td>
</tr>
</tbody>
</table>

Key: Gender: F = female, M = male. Handedness: R = right handed, L = left handed, M = mixed.

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http://www.down-syndrome.info/library/periodicals/dsrp/09/01/
The accuracy and the reaction times were recorded for each of the stimulus, whether it was reversed or non-reversed, was presented with the stimulus at each orientation for a manner identical to the practice trials. Every participant was administered the PPVT-III, a modified version of the Edinburgh handedness test (Oldfield, 1971), and the mental rotation task following the training protocol described below.

**Training protocol**

In order to teach the task to the participant and ensure he/she understood the task, a training session was completed first. Four three-dimensional wooden ‘F’s (two reversed and two non-reversed) were glued to separate circular cards. Two of these ‘F’s, one reversed and one non-reversed were used as references and remained visible to the participant at all times, including during the practice and test trials on the computer. The participant was shown a stimulus on the screen; it was either a reversed or non-reversed ‘F’ glued to the card) at an angle away from vertical, and was asked to physically rotate the card until the ‘F’ was vertical and match it to either the reversed or non-reversed reference ‘F’. When the participant was able to carry this out satisfactorily, he/she was then asked to mentally rotate the ‘F’ in his/her mind and then match it to one of the reference ‘F’s. Once the participant could do this successfully, he/she continued on to the practice trials on the computer.

**Computer task**

A stimulus was presented on the screen; it was either a reversed or non-reversed ‘F’ presented at one of the eight possible orientations. The participant was asked to mentally rotate the stimulus in his/her head until it was upright, to decide if it was reversed or non-reversed, and once a decision was made, to hit the appropriate coded-coded key on the keyboard as quickly as possible. If it was non-reversed, he/she pressed the ‘/’ key which was coloured red; if it was reversed, they pressed the ‘z’ key which was coloured blue. Following 16 practice trials, the participant performed the test trials.

The actual test consisted of 16 trials and was presented in a manner identical to the practice trials. Every participant was presented with the stimulus at each orientation for both the reversed and non-reversed conditions. The pattern of the stimulus, whether it was reversed or non-reversed, the accuracy and the reaction times were recorded for each trial. The stimuli for both the practice and test trials were presented randomly.

**Results**

**Reaction Time**

Table 2 shows the mean (+/- SD) correct reaction times for all 8 orientations and for the reversed and non-reversed conditions for both groups. In the typically developing group, a general trend of increased reaction time with rotation was observed (Figure 2). In the Down syndrome group, a similar trend of increased reaction time with orientation was observed at 135° where the reaction time was faster than 90° and 180°. A 2 (Group: DS vs. TD) x 2 (Pattern: reversed vs. non-reversed) x 5 (Orientation) repeated measures analysis of variance (ANOVA) was performed. For statistical analysis the following 5 specific orientations were used: 0°, 45° (included data from 45° and 135°), 90° (included data from 90° and 270°), 135° (included data from 135° and 225°) and 180°. There was a significant linear effect of orientation F (4, 8) = 12.2 (p = .004). There were no main effects of group, F (1, 13) = 1.87 (p = .192) or pattern, F (1, 8) = 1.694 (p = .200), nor any significant interaction effects.

**Accuracy**

Both groups performed well above chance levels on accuracy (see Table 3). Overall the Down syndrome group were correct on 76% of the trials (SD = 17%) and the typically developing participants were correct on 96% of the trials (SD = 4%). Chance level is 50% for the F-test as participants discriminate between a reversed or non-reversed ‘F’. Figure 3 shows the average accuracy for both groups as a function of orientation.

A 2 (Group: DS vs. TD) X 2 (Pattern: reversed vs. non-reversed) repeated measures analysis of variance (ANOVA) was performed. There were significant main effects of group, F (1, 13) = 5.6 (p = .034) and pattern F (1, 8) = 11.7 (p = .004), but no significant interaction effects.

**Correlation between mental age and accuracy performance**

Within the Down syndrome group, mental age was positively correlated with accuracy on the F-test (Pearson product-moment correlation: r = .816, p < .05) such that increasing mental age was correlated with increased accuracy.

**Discussion**

The primary objective of this pilot study was to determine whether individuals with Down syndrome have the capacity to mentally represent the physical process of object rotation. Several observations of interest came from this data. First, it can be seen that individuals with Down syndrome are able to perform mental rotation tasks well above chance level, indicating that the skill set does develop and does exist, although it may be compromised. Second, mental rotation...
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ability is positively correlated with mental age, suggesting spatial processing skills in the Down syndrome population may be delayed but not arrested. These data challenge the findings of Uecker et al (1994) who suggested that individuals with Down syndrome are unable to perform the task due to arrested development. From our observations, it appeared that providing adequate training trials as well as the experience of physically manipulating the three dimensional wooden ‘F’ was critical to helping individuals with Down syndrome understand the requirements of the task. Wexler, Kosslyn and Berthoz (1998) have shown that the transformations of mental images may in part be dependent on motor processes. It is possible then that having had a number of practice trials in which there was opportunity to physically manipulate and move the object helped to facilitate the subsequent mental rotation.

We are currently exploring whether the process of mental rotation is determined by the nature of the task in individuals with Down syndrome. Ultimately, a procedure incorporating neuro-imaging techniques would allow for more definitive conclusions regarding brain regions involved in the processing of different types of stimuli in the mental rotation tasks in the Down syndrome population. Further research is required to substantiate current speculations and to provide a fuller explanation of mental rotation in people with Down syndrome.

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Correspondence
Dr. Virji-Babul • Centre for Human Movement Analysis, Queen Alexandra Centre for Children’s Health, 2400 Arbutus Road, Victoria, B.C., Canada V8N 1V7 • E-mail: naznin@dsrf.org • E-mail: cjhinnell@hotmail.com

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