Artificial grammar learning in individuals with Down syndrome: the role of prosodic cues

ARTIFICIAL GRAMMAR LEARNING IN INDIVIDUALS WITH DOWN SYNDROME: THE ROLE OF PROSODIC CUES

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ABSTRACT

The artificial grammar learning (AGL) paradigm allows investigation of cognitive processing and learning under controlled conditions. We compared AGL between 17 individuals with Down syndrome (DS) aged 3-12 years and 60 typically developing (TD) individuals aged 5-18 years and examined age effects, whether prosodic cues affected learning, and the effect of familiarity of stimulus sequences.

In general, the TD group strongly outperformed the DS group. In both groups, older children demonstrated better learning. Prosody did not affect learning in the TD group but had a positive effect in the DS group.

While limited by the small group size, our results identify factors that affect or support language learning in DS individuals. This may have clinical and educational implications, as DS individuals may need stimuli augmented with prosodic cues to make them more accessible (e.g., through song).

Keywords: Down syndrome, prosody, artificial grammar, language impairment, learning.

1. INTRODUCTION

Down syndrome (DS) is a developmental disorder which affects approximately 1 in 700 live births [1] resulting from an extra chromosome 21. Individuals with DS are characterized with a range of distinct physiological features including narrow auditory canals, a small oral cavity, short stature, hypotonia, ophthalmological disorders, hearing issues, psychiatric and behavioral difficulties [2]. Individuals with DS have a different cognitive profile from typically developing (TD) individuals, with IQ ranging between 30 and 70, and significant delays with language acquisition.

Infants with DS tend to acquire their first words later than TD children [3]. Development of language beyond the level of single word acquisition has been studied less often and the few existing longitudinal studies on the acquisition of language reached very different results. English speakers with DS were reported to start producing two-word combinations in English around 36 months of age, while Hebrew speaking children with DS started combining words at 55 months [5]. Grammatical acquisition is a challenge and children with DS often score lower than expected for non-verbal mental age on expressive and receptive grammar tasks and on standardized and non-standardized assessments of morphology and syntax [5, 6].

The language input children hear is thought to contain strings of words which are not random but follow the grammatical patterns, or rules, of the target language [7]. While listening to and processing language input, children need to parse the word strings they hear, extract patterns or regularities, and generalize this knowledge to be able to produce and understand new utterances. This language input also contains prosodic cues, which accentuate language structure and are particularly important in the early stages of child language acquisition [8]. In the first few months of life, infants use prosodic cues to help them segment the incoming speech stream into words [9,10]. Opinions are divided as to whether TD 5-year-old children use prosodic cues when disambiguating ambiguous utterances [11,12] because as children grow older, other cues become available, such as segmental and lexical cues [13]. This may be different for children with developmental conditions.

2. ARTIFICIAL GRAMMAR LEARNING

Artificial Grammar Learning (AGL) is an empirical paradigm that allows the investigation of the basic principles underlying the ability to parse combinations of stimuli, extract patterns about their structure and generalize these to novel stimuli [14]. AGL tasks typically involve a familiarization phase where participants are exposed to sentences generated by a (target) grammar, and a test phase, where they judge the correctness of novel sequences. The advantage of AGL is that artificial systems can be designed to be easy to learn through short exposure, and that language features can be controlled.

AGL has been used extensively over the past few decades to study and identify how representations are acquired during learning and what processing biases may be underlying different developmental profiles, and in different developmental and acquired disorders. For example, a study of auditory artificial grammar learning in children and adolescents with Williams syndrome (WS) [15] found that they made decisions on the familiarity of a particular stimulus combination rather than on whether the sequences followed the rules of the target language (grammaticality); this familiarity-based processing was only present in young TD children, while older switched from familiarity- to grammaticality-based judgments. Importantly, the individuals with WS showed evidence of learning only when the stimuli were presented with prosodic cues, unlike the TD individuals.

A reasonable body of literature documents the relative strengths and weaknesses in the language profile of individuals with DS, including difficulties with grammar (e.g., [6,16]). No studies to our knowledge have investigated AGL in individuals with DS using verbal or auditory stimuli in order to determine which factors contribute to learning.

The aim of the current study is to investigate the performance of a group of individuals with DS on a verbal AGL task, how their performance compares to that of TD individuals and determine factors that relate to task performance (age, the presence of prosody in the stimulus set, and processing biases). The research questions were:

- How do individuals with DS perform in an AGL task compared to TD individuals?
- What is the effect of age?
- Does either group benefit from prosodic cues?
- Do participants extract abstract grammatical knowledge, or do they make judgments based on familiarity with stimuli?

3. METHODOLOGY

3.1. Participants

23 participants with DS were recruited through local charities. Six participants were excluded either because they did not complete the AGL, or they showed a strong response bias (i.e., only pressed one of the two keys). The analysis is therefore based on 17 individuals with DS (6 male), with a mean age of 9 years, 7 months (9;7); range 5;10 – 18;4. They had British English as their main language. Children with DS and additional diagnoses were included.

63 TD children, speakers of British English as their main language, were recruited through a participant database at the University of XXXX and from local schools. Three children were excluded from the analyses due to missing data, strong response bias, or failure to complete the task, hence analyses are based on data for 60 children (Mean age = 7 years 5 month; range 3;4 – 12;1; 31 males, 29 females). These participants are the same set as in [15].

3.2. Materials

3.2.1. Baseline assessments

There were two baseline assessments. The non-verbal Raven's Coloured Progressive Matrices (RCPM [17]) assesses fluid intelligence. As individuals with DS are known to have non-verbal cognitive delays, we administered this task to account for non-verbal mental ability. As individuals with DS also present language delays, we measured verbal ability. Depending on a participant's age and their general developmental level, the *Word Structures* subtest of the Clinical Evaluation of Language Fundamentals (CELF-4) or the Pre-School version, CELF-2, were used [18] to assess expressive language ability. We report percentage correct to make the results of the standardised language assessments comparable and also because different versions of the *Word Structures* task have different numbers of items (the pre-school version has 24 and the school version 32).

Table 1 shows participant group demographic information regarding chronological age and their raw scores for the RCPM and CELF percentage correct scores. The groups are not matched on any variables; the TD group are younger on average than the DS group, however the verbal and non-abilities of the TD group are higher than those of the DS group.

	Age in months	**CELF Raw %**	**RCPM Raw**
	Mean (sd) Min-Max	Mean % correct (sd) Min-Max	Mean score (sd) Min-Max
DS (n = 17)	118 (42) 70-221	33 (18) 6-33	13 (4) 3-23
TD (n = 60)	90 (30) 38-145	81 (16) 29-100 (n = 56)	25 (8) 9-36 (n = 59)

Table 1: Participants' age, non-verbal ability and language ability.

3.2.2. The AGL task

Traditional AGL tasks can be too long and complex for children. We designed a novel task which is child-friendly and suitable for individuals with learning difficulties. It has previously been used with individuals with William syndrome [15]. It involves a narrative about a magician trying to learn his spells. Unlike traditional AGL tasks, ours has a prosody and a no-prosody condition.

Children tend to be more attentive if characters appear and move on a screen than if they are only presented auditorily [19]. Auditory stimuli were shown simultaneously with events on a computer screen. A grammatical string in this task had the structure A(B)C, consisting of three-word classes: A, B and C. Class A referred to the object type appearing on screen (e.g., bird, rabbit). Class B, which was optional in a grammatical string, referred to the size or color of the object (big/small, red/blue). Class C referred to an action happening to the object (e.g., it spins or zooms in). Each word class corresponded to one aspect of an event which was presented on the screen. Each word class was distinguished from the others by having a distinct phonological onset, and all words were bisyllabic. Violations were generated by changing the order of word classes, repeating the same word class in a string, or by having both a word order change and a repetition. For a full list of items, see [15].

There were two conditions: *Prosody* and *No Prosody*. These are described in section 3.3.

3.3. Procedure

The task contained a familiarisation and a judgment phase. Familiarisation trials were created and presented through Microsoft PowerPoint using adapted clipart images and animations of a magician and the objects from the artificial grammar scheme. Ten grammatical strings were generated based on the artificial grammar described above using Cepstral's [20] male British English synthesised voice ('Lawrence'). The speaking rate was 136 words per minute. Phrases were sampled at a rate of 44.1kHz, 16 bit stereo with intensity scaled to 70dB.

In the *Prosody* condition, fundamental frequency (F0) fell across the phrase: the F0 of A class words was 125Hz, for B words it was 100Hz, and for C class words it was 75Hz. There was a falling tone on the last word. In the *No Prosody* condition, the F0 of the phrases was kept constant at 100Hz using Praat [21]. Participants were randomly assigned to either the *Prosody* or *No Prosody* condition. 33 TD participants completed the *Prosody* condition and 27 the *No Prosody* condition. In the DS group, 11 participants completed the *Prosody* and 6 participants the *No Prosody* condition.

The experimental trials were created and presented on a laptop computer using Eprime 2.0 Professional (Psychology Software Tools, Inc). There were 20 strings: 10 ungrammatical and 10 grammatical phrases. Of the grammatical phrases, six were identical to phrases from the familiarisation trials, and four were novel, unfamiliar phrases. The ungrammatical phrases consisted of repetitions of word classes or violations of dependency rules (such as a B class word followed by an A class word, which is the opposite of the rule). In the *Prosody* condition, the F0 was the same as the familiarisation trials. Hence, the ungrammatical phrases were distinct from the grammatical phrases acoustically due to an unfamiliar F0, in addition to violations at the grammar level. *No Prosody* condition phrases were presented at 100Hz.

Participants were instructed that they were about to see a magician practising his spells and all they had to do was to watch and listen carefully. They were told the spells would sound funny because the magician comes from another planet. The familiarisation phase lasted approximately 8 minutes. Phrases were repeated on average 10 times (range 9-11) and were presented simultaneously with corresponding animations in the PowerPoint presentation. A simple game was used between each block to maintain participants' attention and motivation.

The test phase followed immediately afterwards. Participants were told that the magician was teaching another magician some spells, and that sometimes these spells would be right and sometimes wrong. The participants had to judge whether spells would work or not by pressing a green smiling face on the keyboard (if they judged a spell to be correct) or a red sad face (if incorrect). Participants received no feedback. When they had completed the task, participants were thanked for listening and asked if they knew which spells would work. Participants commonly responded with: "I was guessing" or "I don't know" suggesting that they had most likely not explicitly extracted a pattern.

Ethical approval was granted by the Research Ethics Committee at the University of XXXX. All participants' parents/carers provided written consent and the participants themselves provided child assent (if children).

4. RESULTS

Accuracy means for all groups AGL task are presented in Table 2.

	Prosody	**No Prosody**
	Mean % correct (sd)	Mean % correct (sd)
DS	48.2 (8.4)	42.5 (2.2)
TD	69.4 (18.8)	69.6 (13.2)

Table 2: Accuracy in the AGL across groups and conditions

A One-Way ANOVA showed an effect of group $F(3,73) = 9.398$, $p < .001$. Tukey's HSD found that for each stimulus condition, the TD group performed significantly better than the DS group was significant ($p < .003$).

We used hierarchical generalized linear models for analysis, with each trial entered as a separate data point. The decision to accept the string ("Accepted") as the binary outcome. We started with simpler models and adding variables if they resulted in significant improvements. For each group separately, we started with Grammaticality, then added chronological age (CA), then Prosody.

Model 1: Accepted ~ Grammaticality

Model 2: Accepted ~ Grammaticality*CA

Model 3 Accepted ~ Grammaticality*CA*Prosody

Model 1 investigated the effect of Grammaticality on responses. In the TD group, the model strength was $\chi^2(1) = 187.48$, $p < .001$ compared to the null model. The effect of Grammaticality was significant, $\beta = -1.65$ (SE = .12), $z = -9.51$, $p < .001$. The odds ratio was 5.19, i.e. TD participants were five times more likely to accept a sequence if grammatical. Model 2, which added CA, was a significant improvement to Model 1, $\chi^2(2) = 54.91$, $p < .001$. Model 3, which added Prosody, did not make a significant contribution compared to Model 2, $\chi^2(4) = 6.19$, $p = .19$, suggesting that the Model 2 is most appropriate. There was a significant interaction between Grammaticality and CA, meaning older TD children accepted more grammatical and fewer ungrammatical strings than younger children.

In the DS group, Model 1 was no significant improvement over the null model, $\chi^2(1) = 1.99$, $p = .15$, with no significant effect of Grammaticality. Model 2, was a significant improvement, $\chi^2(2) = 11.55$, $p = .003$. After entering CA, the Grammaticality effect became significant, $\beta = -1.53$ (SE = .71), $z = -2.14$, $p = .03$. However, there was no significant effect of Age, and no interaction between Age and Grammaticality. Entering Prosody in Model 3 was a significant improvement over the previous model, $\chi^2(4) = 11.7$, $p = .01$.The interaction between Grammaticality and Prosody was significant, $\beta = 4.88$ (SE = 1.81), $z = 2.69$, $p = .007$, meaning that in the Prosody condition, participants with DS more consistently accepted grammatical and rejected ungrammatical strings. A three-way-interaction between Grammaticality, CA, and Prosody was also significant, $\beta = -.03$ (SE = .01), $z = -2.208$, $p = .003$, showing a greater effect of Prosody on grammaticality judgments in older participants.

To test the effect of familiarity, we calculated Edit Distance (ED) for each string, a measure of how similar one test string is to the most similar familiarization string. Replacing Grammaticality with ED resulted in weaker models for both groups.

5. DISCUSSION

Individuals with DS were less successful in the AGL task than the TD group, despite having a higher average chronological age. The best fitting statistical model implies that participants with DS were more successful if they were older and the stimuli contained prosody. The positive effect of prosody on learning was stronger in older children with DS.

The TD group, however, reliably based decisions on the grammaticality of strings, with no effect of prosody. However, older children performed better than younger children. Age effects are in line with existing results [22,23].

We found that both groups were more likely to make judgment based on grammaticality than on familiarity of strings. This suggests that language in children with DS although delayed, may not be qualitatively different from neuro-typical children.

Prosody had a facilitatory effect for the individuals with DS only. This is similar to XXXX et al. [15], which also showed that prosody also had a facilitatory effect on the AGL for children and adolescents with WS. These findings can be interpreted within the speech segmentation hierarchy proposed by Mattys et al. [13] according to which prosodic cues are the lowest in the hierarchy (lexical cues and segmental cues being higher) and, as such, they are thought to be the earliest and most critical in the early stages of language acquisition. A large body of evidence shows that prosodic cues play a crucial role during young children's speech processing in helping them identify between phrase boundaries and structural relations between phrases (e.g., [9,10]). Given that individuals with DS present with significant delays with language acquisition, it seems likely that they need prosodic cues to help them with a language learning task. This has implications for language interventions for individuals with DS, as it suggests that adding prosody, or making language stimuli more prominent, may aid learning. This is unsurprising, as prosody is a fundamental part of human language.

This study has limitations. The DS group is small, partially because 25% of the recruited participants with DS we recruited were unable to complete the task. Future studies interested in this research should seek replication.

6. REFERENCES

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