UNIVERSITY OF PADUA

Department of General Psychology

Master's Degree in Cognitive Neuroscience and Clinical Neuropsychology

Final Dissertation

Bootstrapping Word Order in Down Syndrome:

A Turkish Psycholinguistic Study

Supervisor

Professor Judit GERVAIN

Co-supervisor: Mohinish Shukla

Candidate: Elvan INCE

Student ID number: 2014315

Academic Year 2022/2023

For my family, without them, I would not be here as I am right now.

For the people who died, who lost their families, and loved ones in the earthquake in Türkiye.

Acknowledgements

This thesis would not have been possible without the love, support, and encouragement I received from my supervisor, professors, parents, relatives, and friends. I have benefited greatly from the mentoring of Prof. Judit GERVAIN, my supervisor, and Prof. Mario BONATO, my professor, I am thankful to both. Also, I would like to thank my mother Prof. Gonca INCE for the help and support I received. I also would like to acknowledge my dear father Iskender INCE and my grandmother Saniye INCE for all their support in my studies and Stefano PALUMBI for believing in me. Lastly, I am thankful to all the parents and children from all over Turkey for their interest, time, and participation in my study and for their support during the whole process.

I worked on language acquisition mechanisms because of what I saw in my professor, Prof. Judit GERVAIN; her devoted and enthusiastic way of teaching has led me to discover the fascinating side of developmental psychology and language, and this has led me to have a great interest in this field. I am truly grateful to all my professors in my faculty to open a door to my future career and for their support and advice during my master's education.

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Abstract

Down syndrome (DS) is a genetic condition resulting in problems with hearing, oral-motor, cognitive, social, prelinguistic and early nonverbal communication abilities. Language is one of the most severely compromised areas of cognitive functioning. It is essential to better understand how individuals with DS perceive, process, and learn their native language to develop effective intervention strategies. The current study seeks to contribute to this understanding, focusing on whether individuals with DS aged between 1 to 20 years learning Turkish show sensitivity to cues to the basic word order of their native language, which typically developing (TD) children are known to recognize at 7 months of age (Gervain et al. 2008). Particularly, TD infants identify frequent words as grammatical functors (e.g., articles, prepositions, pronouns such as the, on, up, he, it etc.) and use this frequency information to bootstrap the relative order of functors and content words in their native language. By utilizing an online version of the head-turn preference paradigm (HPP) which is the first implementation of a gaze-contingent using an online platform to an artificial language learning experiment similar to the one used in the original study (Gervin et al. 2008), we assessed whether individuals with DS show a similar sensitivity to the basic word order of their native language. Using this online paradigm with an atypically developing population is a further methodological challenge that our study addressed. Our results show that Turkish individuals with DS preferred i.e., showed longer looking times to, frequent final test items, as predicted, reflecting the function-word final order of Turkish. This result suggests that individuals with DS may be able to exploit some of the basic cues to the grammar of their native language and have better language perception and comprehension skills than previously believed.

Keywords: Down Syndrome, Language Acquisition, Frequency-Based Bootstrapping, Word Order, Gaze-Contingent, Head-Turn Preference Procedure Online

1. Introduction

Hearing a baby's first word is precious and puts a large smile on people's faces around the baby. From birth through childhood and adolescence, a child learns the essentials for becoming an adult. It is fascinating to see and experience the milestones of development emerging step by step. Some functions are acquired in the first years of life, such as learning to walk and talk. Even if we perform these essential tasks relatively easily as adults, these achievements need to be acquired within a baby's world. While we now have a basic understanding of the mechanisms guiding such achievements in typical development, atypical development may follow a different course, which often remains poorly understood.

One of the big steps in the journey of development is acquiring the native language. In addition to being an essential developmental achievement, future social functioning, and learning are also derivatives of a person's language skills (Smith, Hokstad, & Næss, 2020; Næss, Nygård, Dolva, Ostad, & Lyster, 2016; Hulme et al., 2012; Boudreau, 2002). Language trajectories for typical development have been relatively well identified. For instance, typically developing (TD) children differentiate phonemes universally at birth, become perceptually attuned to their native language between 10 and 12 months of age (Kuhl, 2010; Werker & Tees, 1984), and start to comprehend and pronounce words, and use representational and deictic gestures at this age (Caselli, Rinaldi, Stefanini & Volterra, 2012; Fenson et al., 1994). TD children at 18 months have a vocabulary of about 50 words and commonly utilize gesture-word combinations. Subsequently, they develop a larger expressive vocabulary and begin to combine words between 20 and 24 months of age (Capirci & Volterra, 2008; Fenson et al., 1994). By 3 years of age, they start creating complex and increasingly more adult-like utterances (Guasti, 2017). It is crucial to recognize these milestones since biological, cognitive, and environmental variables can cause language delay

(Filipe, Cruz, Veloso, & Frota, 2022; Riva et al., 2017; Perani et al., 2011; Kuhl, 2010; Zubrick, Taylor, Rice, & Slegers, 2007; Reilly et al., 2007).

Our knowledge of language acquisition in various developmental disorders, however, remains limited. Therefore, this thesis aims to better understand the mechanisms children with Down syndrome use to acquire language, particularly a fundamental grammatical feature, the basic word order of their native language.

1.1. Down Syndrome and Language in Current Knowledge

Down syndrome (DS) is the most common genetic condition occurring in 1 out of 700/1000 live births (Fidler, 2005; Stoll, Alembik, Dott, & Roth, 1990; Hassold & Jacobs, 1984). An extra copy of chromosome 21 accounts for ninety-eight per cent of occurrences of Down syndrome (Trisomy 21). Down syndrome can occur regardless of race, social standing, or geographical region. Increased maternal age is the sole etiological factor that is firmly connected to Down syndrome (Patterson & Lott. 2008; Hassold & Sherman, 2002).

DS results in anomalies in several organ systems as well as in distinct behavioural patterns and problems with hearing, oral-motor, cognitive, social, prelinguistic and early nonverbal communication abilities. Language is one of the most severely compromised areas of functioning. In the following section, we examine the literature on some of the characteristics of DS which influence language development.

1.1.1. Hearing Abilities

One of the characteristic features of DS is hearing difficulties. Hearing is instrumental to language development as the input for language acquisition is spoken language. Conductive hearing loss, sensorineural hearing loss, or both affect about two-thirds of children with DS (Roizen, & Patterson, 2003). Infection-associated hearing loss may provide an additional risk factor (Martin, Klusek, Estigarribia & Roberts, 2009; Roberts et al., 2004). Hearing loss in DS has been found to be associated with problems in vocabulary growth and the acquisition of grammatical morphemes (Miolo, Chapman & Sindberg, 2005).

1.1.2. Oral Motor Characteristics

Individuals with DS have skeletal and muscular differences as compared to TD peers (Leddy, 1999). They may have excess or reduced face muscles, a larger tongue, and bone malformations in the oral structures. Additionally, their oral cavity is smaller and more posterior than in TD children. Their speech production abilities are limited by these structural alterations. Moreover, lip movement is restricted by weak facial muscles, which affects the generation of labial consonants and rounded vowels. Lip and tongue motions involved in all characteristics of speech production are impacted by general hypotonicity. Each of these aspects might adversely affect a child with DS's articulatory and phonatory abilities by affecting the motor movements connected to speech (Stoel-Gammon, 2001).

1.1.3. Cognitive and Language Domain

Individuals with DS have an IQ range between 30 and 70, and around 80% of them have a moderate intellectual impairment (Pueschel, 1995). Children and teenagers with DS may have reduced mean length of utterance (MLU), trouble reading, and impaired phonological memory abilities (Laws, 1998, 2004). Significant impairments in both working memory (WM) and long-term verbal memory have been documented. Importantly for our study, speech and language abilities are affected more than visuospatial processing abilities, which are often seen as a relative strength. (Knowland & Thomas, 2011; Fidler, Hepburn, and Rogers, 2006; Jarrold, Baddeley & Hewes, 1999; Carlesimo, Marotta, Vicari, 1997; Wang & Bellugi, 1994). According to Laws (2002), there is strong evidence that hearing loss or speech issues cannot account for verbal WM difficulties.

Past studies indicated that compared to verbal WM, visuospatial WM is better maintained in DS. According to a more recent study (Carretti, Meneghetti, Doerr, Toffalini, & Lanfranchi, 2022), individuals with DS performed better in a spatial-sequential WM task than in a spatial-simultaneous WM task similarly to mental age-matched TD peers. Additionally, they exhibited linearly increasing task scores for both spatial WM components up to 13 years of chronological age, then this developmental trend followed a flattened course. Moreover, the results pointed to a positive correlation between performance in both spatial WM components and verbal, and visuospatial developmental levels in DS. (Carretti, Meneghetti, Doerr, Toffalini, & Lanfranchi, 2022).

1.1.4. Social Abilities

One of the essential foundations of language development is social interaction. Between 0–4 years, children with DS appear to have social skills appropriate for their mental age (Dykens, Hodapp, & Evans, 1994). Children with Down syndrome are frequently described as being very social, engaging, and affectionate (Moore, Oates, Hobson & Goodwin, 2002). Compared to language abilities, socializing seems to be a relative strength (Dykens, Hodapp, & Evans, 2006; Fidler, Hepburn, & Rogers, 2006).

Yet, some individuals with DS may have impaired social skills. DS is sometimes co-morbid with autism spectrum disorder (ASD) characterized by repetitive behaviours as well as social and communication problems (Godfrey et al., 2019). The prevalence of comorbidity with ASD is 1 in 20 (Capone et al., 2005; Kent, Evans, Paul & Sharp 1999).

Depression and other psychiatric disorders impacting social skills are more prevalent in people with DS than in the general population, but less common than in individuals with other types of intellectual disability (Roizen & Patterson, 2003). Early onset dementia in DS starting from age 45 years may also cause a decline in social skills and an increase in maladaptive behaviours (Urv, Zigman, & Silverman, 2008).

1.1.5. Prelinguistic and Early Nonverbal Communication Abilities

Children with DS typically start producing a variety of consonants and vowels during the first years of life, as well as repeated consonant-vowel combinations (reduplicated, canonical babbling) at approximately 9 months of age (Lynch, Oller, Steffens & Levine, 1995) which may be prolonged till 24- months (Stoel-Gammon, 2001). Despite this relatively typical prelinguistic development, infants with DS show substantial variability and often delays in producing their first words which may occur at a typical developmental schedule at the end of the first year of life or as late as 7 years of age (Stoel-Gammon, 1998; Gundersen, 1995).

Although gesture use was previously believed to be relatively preserved in DS, a longitudinal study by Zampini and D'Odorico (2011) demonstrated that children with DS engage in prolonged gesture use to cope with verbal production difficulties. Two developmental trajectories of gesture production have been observed: an “increasing profile”, characterised by an increase in gesture production frequency from 24 to 48 months and an “inverted U-shaped profile”, with an increase in gesture production frequency or a fixed production of gestures from 36 to 48 months following a gradual decrease in gesture use. Children with an inverted U-shaped profile of gesture development showed considerably higher growth in their lexical abilities and higher frequency of word production at both 36 and 48 months similar to TD peers.

Joint attention, an interaction where the child and the caregiver attend to the same object or event as well as to one another, is an early social-communicative mechanism that contributes to language development in typical development (Tomasello, 1995). Engagement in joint attention between the chronological age of 18–22 months and non-verbal mental age of 14 months has been shown to play a role in the language development of children with DS as well, and it has found to be positively correlated with language skills at 17–23 months (Seager et al., 2018). Also, a meta-analysis has demonstrated that children with DS show comparable joint attention abilities to TD peers (Hahn, Loveall, Savoy, Neumann & Ikuta, 2018).

Language problems may be the biggest obstacle to independent, meaningful engagement in the community for people with DS (Laws, Byrne, & Buckley, 2000; Abbeduto, Warren, & Conners, 2007). Because of considerable language-related difficulties (Smith, Hokstad, & Næss, 2020; Næss, Lyster, Hulme, & Melby-Lervåg, 2011; Martin, Klusek, Estigarribia, & Roberts, 2009), individuals with DS often invest a lot of time and effort in interventions. Nevertheless, the efficiency of language interventions varies across studies. There are not many commonalities among effective techniques and individual variation in responsiveness to therapies remains unknown (Smith, Hokstad, & Næss, 2020). Therefore, improving language in children with DS is crucial for long-term positive outcomes (Smith, Hokstad, & Næss, 2020). The benefit of language interventions is often underestimated due to the intellectual disabilities in DS (Turner & Alborz, 2003). It is thus important to develop better intervention techniques (Seager, Sampson, Sin, Pagnamenta, & Stojanovik, 2022; Smith, Hokstad, & Næss, 2020; Van Duijn, Dijkxhoorn, Scholte, & van Berckelaer-Onnes, 2010).

To do so, we first need to better understand how children with DS perceive, process and learn the language. The current study seeks to contribute to this understanding, focusing on speech perception, an area that is strongly understudied in DS, as most existing studies focus on language production (Seager, Sampson, Sin, Pagnamenta & Stojanovik, 2022; Smith, Hokstad, & Næss, 2020; Smith, Næss & Jarrold, 2017; Laws & Bishop, 2004; Windsor, 1999).

1.2. Language Acquisition and Bootstrapping Word Order

One of the early steps of language acquisition is learning word order. TD children show rudimentary knowledge of the relative order of function words (grammatical words such as articles, pronouns, prepositions etc., e.g., *the*, *it*, *she*, *on*, *down* etc.) and content words (words carrying lexical meaning such as verbs, nouns etc., e.g., *run*, *eat*, *love*, *turtle*, *baby* etc.) in their native language as early as 8 months of age (Gervain et al., 2008).

Languages of the world differ in the relative order of function and content words, which correlates with other word order phenomena, for instance, the relative order of the Verb and its Object (Dryer 1992). In functor-final languages, like Turkish and Japanese, functors follow content words (e.g., Turkish: *masa-da* table-on, i.e., "on the table") and Objects precede their -Verbs (OV, e.g., Turkish: *Ben bir elma yerim,* I an apple- eat. i.e., "I eat an apple"). By contrast, languages like English and Italian have functor-initial order (e.g., prepositions precede nouns, Italian: *sul tavolo,* on-the table, i.e., "on the table") and Verb-Object (VO) order (e.g., Italian: Mangio *una mela* eat-1sg an apple, i.e. "I eat an apple"), Functors are very highly frequent in language, and since infants are sensitive to frequency information, they can detect some of the most frequent functors and track their location in utterance-initial or -final positions to determine the relative order of functors and content words in their native language and with that, all other correlated word order phenomena.

In a study by Gervain et al. (2008), it has been demonstrated that infants exposed to Japanese and Italian, two languages with opposite word orders, showed sensitivity to the frequency distributions and word orders of their native language. The study used an artificial grammar (Table 1) with strictly alternating frequent and infrequent words, which mirrored the distribution of functors and content words in natural language. The artificial grammar stream was made up of repeated concatenations of an AXBY four-syllabic basic unit in which A and

B were frequent syllables mimicking function words, and X and Y were infrequent syllables mimicking content words. The categories A and B each contained a single syllable, *fi* and *ge*, respectively, while the categories X and Y had 9 different syllables each, thus individual X and Y syllables were 9 times less frequent than A and B syllables (Table 1A).

Gervain et al. (2008) familiarized 8-month-old Japanese and Italian infants with a 4-minute-long continuous stream derived from the artificial grammar, in which the AXBY basic unit was repeatedly concatenated, creating a strict and continuous alternation of frequent and infrequent syllables. The beginning and the end of the familiarization were ramped in amplitude, thus the first and last syllables could not be identified. As a result, the continuous stream could be parsed into two possible orders, i.e., was ambiguous between two possible underlying word orders: a frequent-initial AXBY order and a frequent-final XBYA order. After 4 minutes of familiarization with this ambiguous speech stream, Japanese and Italian babies were tested with eight four-syllabic ‘sentences’ of the artificial language (Table 1C), four frequent-initial (AXBY), four frequent-final (XBYA) sequences. As the familiarization was completely ambiguous, if infants showed any preference for either of the word orders, then this could only derive from their knowledge of the word order of their native language. The study used the Head-turn Preference Paradigm (HPP; Saffran, Johnson, Aslin & Newport, 1999) to assess infants’ looking time preference for the two different test item types., Infants were tested while sitting on a parent’s lap in a dimly lit, sound-attenuated cubicle in a laboratory environment.

Table 1

Artificial Grammar

(A) Lexicon	A: [fi] X: [ru, pe, du, ba, fo, de, pa, ra, to] B: [ge] Y: [mu, ri, ku, bo, bi, do, ka, na, ro]	
(B) Familiarization	**...AXBYAXBYAXBYA...** ...**ge**fo**fi**bu**ge**de**fi**ko**ge**pa**fi**mo**ge**...	
frequent-initial	...**ge**fo**fi**bugede**fi**ko**ge**pa**fi**moge... OR	
frequent-final	...gefo**fi**bu**ge**defikoge pa**fi**mo**ge**...	
(C) Test Items	*frequent-initial*	*frequent-final*
	fifo**ge**bi	ba**ge**bo**fi**
	firu**ge**mu	ka**fi**pa**ge**
	gedo**fi**de	ku**fi**du**ge**
	geri**fi**pe	ra**ge**na**fi**

Table 1. Artificial language used in Gervain et al. (, 2008). (A) The syllables used in the four categories. (B) The familiarization steam. The first line shows the underlying structure. The second line demonstrates a piece of the familiarization steam. The third and fourth lines indicate the two potential 'word orders' of the stream. (C) The test items are listed under their respective 'word order'.

The authors found an interaction between language and word order. Italian and Japanese infants engaged in opposite-looking patterns in which the Japanese group looked significantly longer at the frequent-final items, whereas the Italian group showed the opposite pattern looking more at the frequent-initial ones (Gervain et al., 2008). In other words, they showed a preference for the word order that characterized their native language. Since the familiarization and test stimuli were identical for the two groups of infants, this difference can only arise because infants already at this age have some basic knowledge of the word order of their native language.

In sum, Gervain et al. (2008) and subsequent work (for a recent review, see de la Cruz-Pavía et al. 2021), showed evidence for a frequency-based mechanism to bootstrap word order using functor and content words suggesting that infants might be using word frequency to construct the first representation of word order. These results also suggest that acquiring word order begins before infants acquire a sizeable lexicon and it is, thus, independent of lexical knowledge. Therefore, it is not unconceivable that learners who have language delays or impairments such as individuals with DS may also be able to use this mechanism to bootstrap word order. The current study will test this possibility.

1.3.The Current Study and Hypothesis

In the current study, the aim is to extend existing research on the role of function words in acquiring, analysing, and learning new language-related material to the atypically developing population of individuals with DS. The frequency-based bootstrapping mechanism (Gervain et al., 2013; Gervain et al., 2008) has been investigated with TD populations. However, to our knowledge, it has never been studied with atypical populations, thus the study aims to understand strategies based on distributional cues engaged by individuals with DS. By testing individuals with DS from a broad age range (between 1 to 20 years), we would like to explore the continuity, possible changes, and trajectories of this mechanism.

The first hypothesis we test in this study is that the frequency-based approach will generalize to atypical development. We test this hypothesis with Turkish-exposed DS participants because functor-final languages like Turkish have been understudied in the developmental literature in general and with respect to frequency-based bootstrapping in particular. Since Turkish is a functor-final language, we predict that our participants will have a preference for, i.e., longer looking times to, frequent word final test items. The second hypothesis is that this ability may change over the course of development, i.e., between 1 and 20 years.

As Turkish-exposed DS individuals are not available in Padova, we needed to conduct our study online. Existing online experimental platforms, however, do not allow for gaze-contingent testing, i.e., presenting/selecting stimuli as a function of the participant's gaze on the screen in real-time. We have thus relied on Artemis, a testing interface newly developed in our laboratory (Shukla et al., in preparation) designed to do exactly this. Our study is thus innovative from a methodological perspective, as well as implementing a gaze-contingent online testing interface with DS participants for the first time.

2. Method

2.1. Participants

33 Turkish individuals with DS took part in the study (12 females, 21 males). Their mean chronological age was 10 years and 5 months (SD = 6 years, ranging between 1 year and 5 months, 20 years, and 5 months). All participants had mild to moderate intellectual disability due to DS. None of the participants had current ear infections and they all had normal hearing except for 3 participants 1 who reported severe (80%) and 2 who reported mild to moderate (25%) hearing loss, and all three had hearing aids. An additional 39 individuals were tested, but not included in the analysis for the following reasons: failure to complete the experiment due to not being able to sustain attention during the required time of the session (N = 10), internet connection issues (N = 2) and technical problems (N = 27). A parent of each participant gave informed consent before the participation. The study was approved by the Ethics Committee of the University of Padua.

2.2. Materials

2.2.1. Stimuli

The artificial grammar used in Gervain et al. (2008) and subsequent work was also used in the current study (Table 1). The artificial language consisted of four syllable-long basic units: AXBY, where A and B represent constant syllables, while X and Y come from two categories containing 9 syllable tokens each, mimicking function, and content words, respectively. A 3 min 53 s long familiarization was created from the syllables by repeating 243 times the four-syllabic basic (each potential _X_Y syllable combination had been used 3 times).

Table 2

Test Items

frequent-initial				***frequent-final***			
A	X	**B**	Y	X	**B**	Y	**A**
fi	fo	**ge**	bi	ba	**ge**	bo	**fi**
fi	ru	**ge**	mu	ka	**fi**	pa	**ge**
ge	do	**fi**	de	ku	**fi**	du	**ge**
ge	ri	**fi**	pe	ra	**ge**	na	**fi**

Table 2. Test items used in "Bootstrapping word order in prelexical infants: A Japanese–Italian cross-linguistic study," by J. Gervain et al., 2008, *Cognitive psychology, 57*(1), 56-74. Frequent A & B and infrequent X & Y syllables reflect function and content words, respectively.

The fr4 female diphone database of the MBROLA (Dutoit, 1997) text-to-speech synthesizer with a monotonous pitch of 200 Hz and a constant phoneme duration of 120 s was used in the production of the familiarization stream as well as of the test items. Phrase information was suppressed by increasing the volume of the initial and final 15 s of the familiarization stream, resulting in an ambiguous structure that could be parsed as either frequent-initial (AXBY) or frequent-final (XBYA) (Table 1B).

Eight four-syllabic 'sentences' of the language were used as test items (Table 1C). Four of them followed the frequent-initial order (AXBY), and the other four the frequent-final order (XBYA). The same test item was repeated 15 times during a test trial with 500 ms pauses in between. The 8-test trials were presented in a randomized and counter-balanced order across participants, with the constraint that a maximum of two subsequent trials could be of the same condition, i.e., word order type (frequent-initial/frequent-final).

2.2.2. The Online Testing Interface: The Artemis Project

The online experiment, conducted on the Artemis Project experimental interface, including the gaze recognition algorithm, was created, and programmed by Mohinish Shukla (Shukla et al., in preparation). The Artemis Project intends to overcome the challenges related to the reduced number of recruits in the BabyLab due to the COVID pandemic. Moreover, it can be used to extend research to participant groups who are not available for in-lab testing, e.g. participants exposed to different languages, having a different socio-economic status or neurodevelopmental differences, who can benefit from online participation.

The web-based experimental system, Artemis, is hosted by the University of Padova servers. Components of the current Artemis system are Javascript, including the Phaser framework, to provide fast client-side stimulus presentation, Python, including Flask and MediaPipe for recognizing faces and annotating facial landmarks in webcam streams on the server, and standard HTML and CSS for building the required web pages (Shukla et al., in preparation).

2.3. Procedure

The study was conducted online. Every participant was tested in their preferred space using a personal computer. While younger participants were sitting on a parent's lap, older participants performed the study independently (Figure 1). Participants or their legal representatives (parents/guardians) first gave informed consent online to participate. The Head-turn Preference Paradigm described by Saffran, Johnson, Aslin and Newport (1999) was used to test participants' word order preferences.

Figure 1A

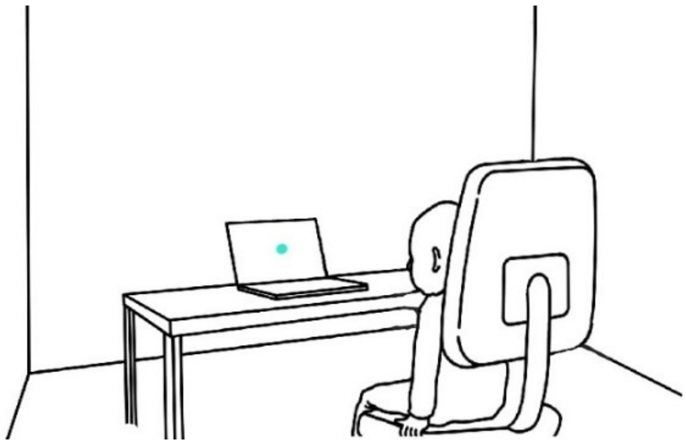

Figure 1B

Figure 1. The figures above illustrate the experimental settings for different age groups. While Figure 1A demonstrates younger participants sitting on a parent's lap, Figure 1B represents older participants performing the study independently.

The participants' faces were positioned in front of the webcam centred on a window showing the webcam output. After clicking the start button, the experiment started. Participants first listened to the approximately 4-minute familiarization stream while a video imitating blinking lights appeared randomly at the two sides or the centre of the computer screen as attention getters. The blinking light videos varied randomly in colour between green or yellow to make the attention-getters more engaging. There was no relation between the lights and the sounds, whereas the presentation of the lights was dependent on the participants' looking behaviour, as is the case in the lab-based HPP. The blinking light appeared randomly at one of three locations on the screen (left, centre or right) and continued until the participant looked away for more than 2 sec. Participants' looking behaviour was analysed automatically by a built-in face- and gaze-recognition algorithm that identified where the participant was looking (Figures 2 and 3).

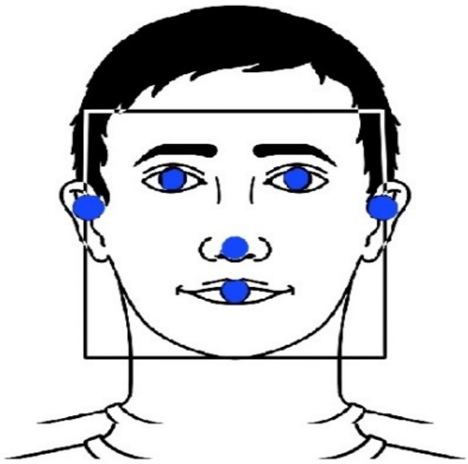

Figure 2. The illustration shows built-in face- and gaze-recognition reference points.

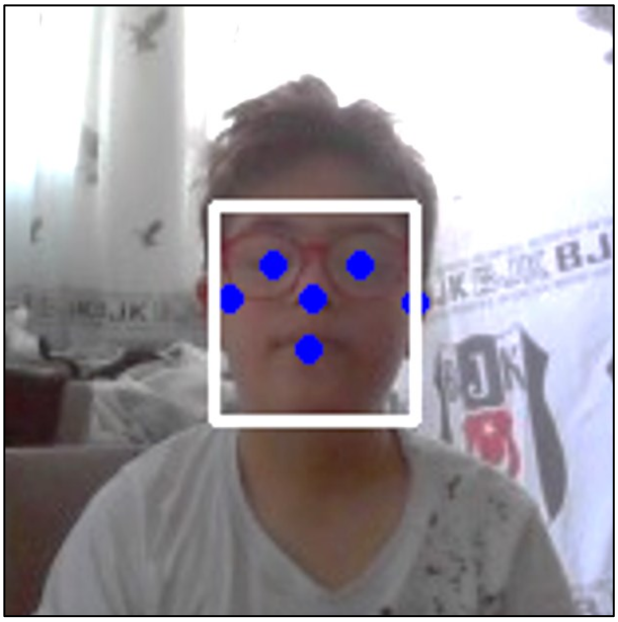

Figure 3. A screenshot of built-in face- and gaze-recognition reference points showing when a participant's face and eye gaze was detected by the algorithm during the experiment, designed by Mohinish Shukla, 2023, The Artemis Project: a Gaze-Contingent Testing Site for Online Studies with Infants. [Manuscript in preparation].

Participants performed 8 test trials right after the familiarization. At the beginning of each test trial, a central blinking light was used to attract attention to the centre. After attention was established, one of the side lights started blinking and the central light was terminated. Once participants attended to the side light, a test item was played repeatedly 15 times for a total of about 22 sec or until the participant looked away for more than 2 seconds. If either of these conditions were met, the trial ended and a new trial began. The order and side of the presentation of the test items were randomized and counterbalanced across participants. The entire procedure was a close adaptation of the lab-based HPP used in

Gervain et al. (2008) and subsequent work. Apart from the online modality, the only difference was that the three locations for the lights were in front of the participant on a single screen, rather than being in front and on the two sides. However, a single-screen setup with all three locations in front of the participant has already been successfully used in lab-based HPP studies testing artificial grammars (Gonzalez-Gomez et al., 2019; Ladányi et al., 2020). The Artemis software automatically measured looking times.

3. Results

Participants' looking times (Figure 4) were averaged across all trials of the same type (frequent-initial/frequent-final). The data was not normally distributed as indicated by the Shapiro-Wilk test for the looking times in the frequent- initial, W (33) = 0.71, p = .000 (skew 2.336) and frequent-final W (33) = 0.89, p = .003 (skew 1.076) conditions, which is an expected and well-documented property of developmental looking time data (Csibra et al., 2016; Leslie & Chen, 2007; Farroni et al., 2005). The data was thus log-transformed, as suggested in the literature (Csibra et al., 2016).

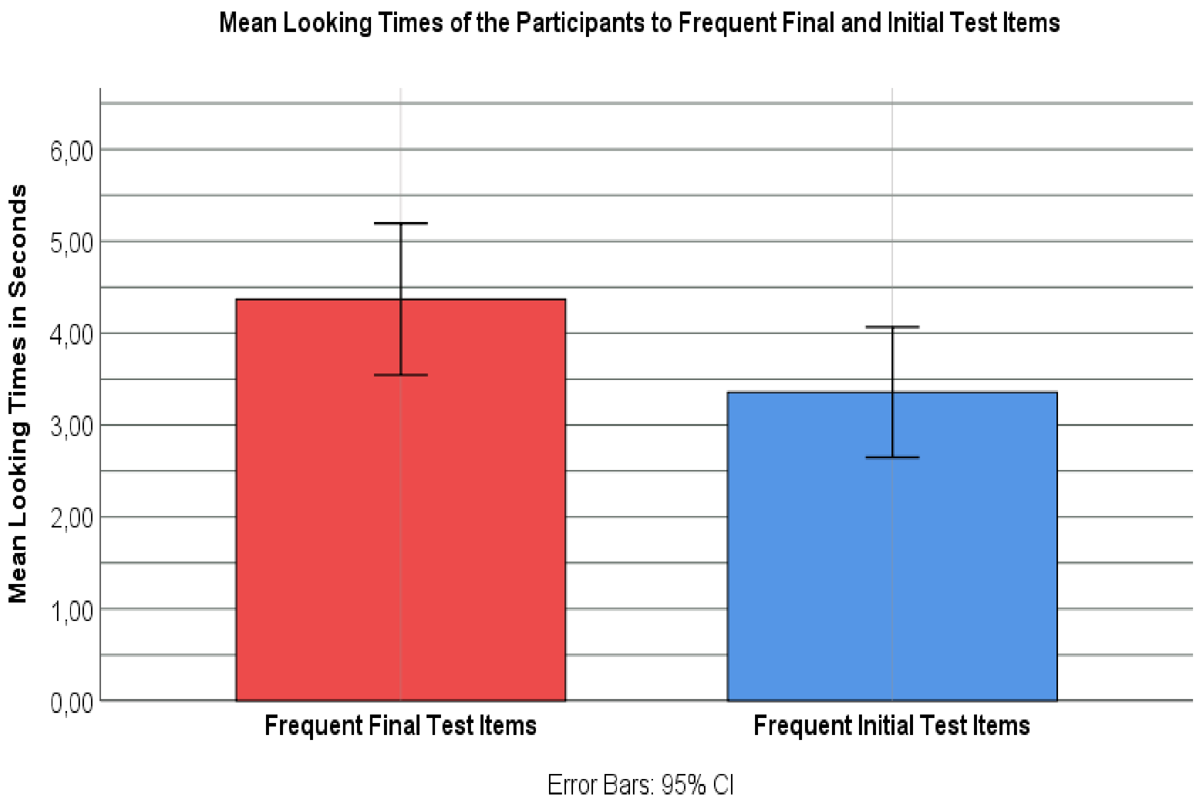

Figure 4. A bar graph representing the mean-looking times of the participants.

To assess whether participants' looking times differed for frequent-initial and frequent-final test items, a paired sample t-test, robust against non-normality, was conducted on the transformed data. The test indicated that there was a statistically significant difference between the looking times for frequent-initial (M = 0.474, SD = 0.201) and frequent-final (M = 0.583, SD = .228) items, (t (32) = -2.502, p = .018). The effect size was Cohen's d = -0.51, a medium-sized effect.

Figure 5 shows the looking times as a function of age. To assess the effect of age on word order preferences, we conducted a repeated measures analysis of covariance (ANCOVA) with Test Item Type (frequent-initial/frequent-final) as a within-subject factor and Age as a covariate. The main effect of Test Item Type was not significant, F (1, 31) = 1.597, p = .216, partial eta-squared = .049. There was also no significant effect of Age, F (1,31) = .004, p =.952 partial eta-squared = .000.

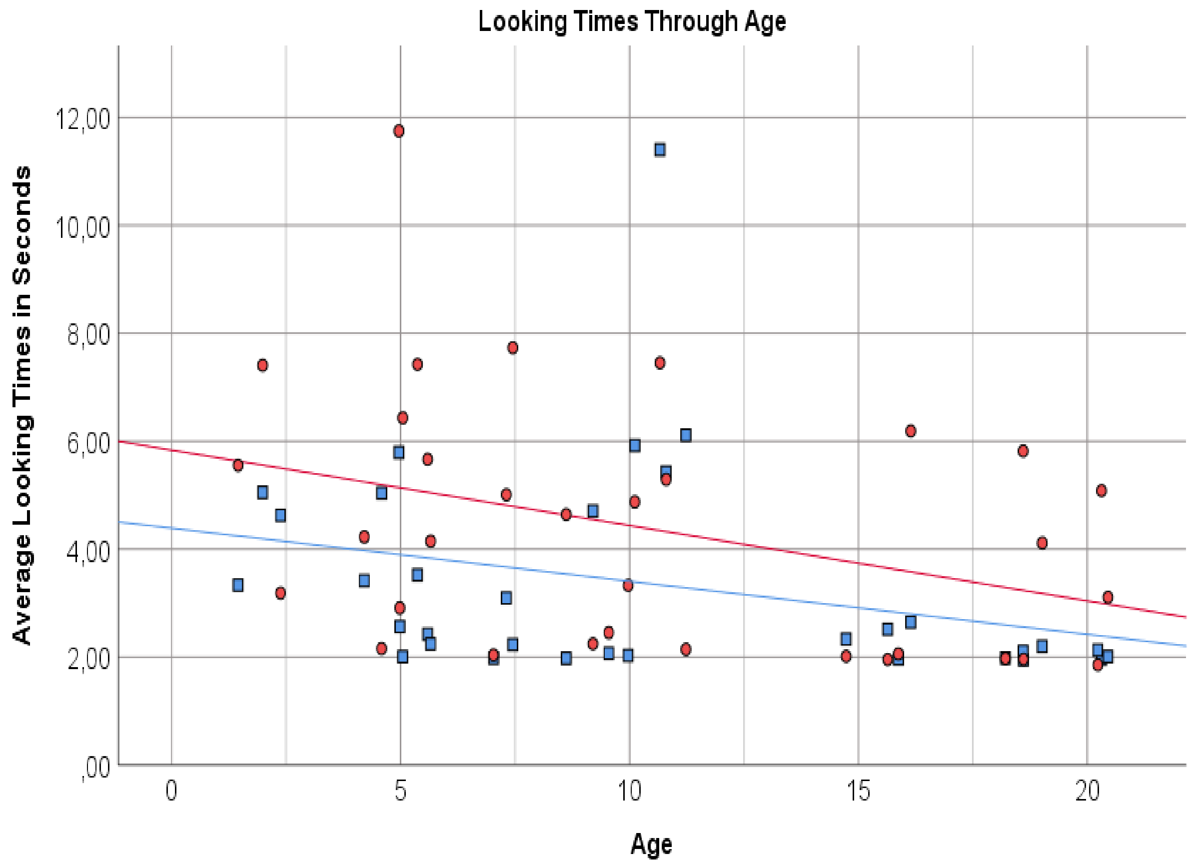

Figure 5. Figure 5. Scatter plot representing the mean-looking times of the participants as a function of age in the two conditions. Red circles indicated the mean-looking times to frequent-final test items, with the linear regression line overlaid in red (R^2 = .130), blue squares represented the mean-looking times to frequent initial ones, with the linear regression line overlaid in blue (R^2 = .088).

4. Discussion

The present study aimed to investigate frequency-based word order acquisition and processing in individuals with DS. We tested Turkish participants with DS aged between 1 to 20 years. For the first time, we used a gaze-contingent HPP interface to test participants online, ensuring access to Turkish participants and a large sample size.

First, our findings showed that Turkish individuals with DS preferred the frequent word final word order, characteristic of their native languages. These results are in line with those obtained in TD populations with infants and adults in the previous studies (Gervain et al., 2013; Gervain et al., 2008) that demonstrated a clear preference towards word orders resembling participants' native language. The current study likewise demonstrated that individuals with DS engage in the frequency-based approach to acquire word order alike the TD population. Considering that the frequency-based bootstrapping mechanism could be a powerful learning strategy for acquiring syntax later (Gervain et al., 2008), the current results suggest that individuals with DS might have better language perception and comprehension skills than previously believed. This could be attributed to their ability to recognize basic cues to the grammar of their native language.

Moreover, when age was controlled, it did not seem to influence the preference for word order. This finding showed evidence in previous studies done with TD populations of different ages as well (Gervain et al., 2013; Gervain et al., 2008).

In summary, acquiring word order and learning language-related information using frequency cues is present in DS like in typical development, confirming our hypothesis that the frequency-based bootstrapping mechanism could be engaged in atypically developing populations, as well.

Methodologically, we utilized a gaze-contingent HPP interface to conduct the current study online. This innovative method enabled us to obtain results that align with data collected in previous lab studies. Moreover, we were able to extend participation to individuals who may not have had the opportunity to contribute in a traditional lab environment. Notably, our study had a substantial sample size, which is particularly crucial, but very challenging to achieve for developmental studies investigating atypical populations.

From an applied and clinical point of view, individuals with DS and practitioners could benefit from our results. The findings highlight a hitherto unknown strength of the DS population and may help to create better interventions that consider the cognitive strengths of those with DS. This, in turn, could pave the way for more appropriate and better-suited therapeutical and educative options that can help prevent or offset potential negative outcomes later in life.

Although these results are new and interesting, a few limitations need to be acknowledged. The data we collected was cross-sectional and not longitudinal. We thus do not know how the perceptual sensitivity to word frequency and word order influences actual language development in individuals with DS. Future research could follow up the individuals with DS longitudinally to better describe individual developmental trajectories and the role frequency-based bootstrapping may play in language development in DS. Further, the study should be replicated, and similar studies should be conducted with DS individuals exposed to languages other than Turkish. Lastly, in addition to chronological age, using mental age as one of the parameters could reflect better the developmental timeline of acquiring and processing word order.

5. Conclusion

Cognitive functioning has relative strengths and weaknesses in individuals with genetic neurodevelopmental disorders. The current study focused on data from various developmental stages of individuals with DS to highlight a possible frequency-based mechanism that they may engage in to acquire and process word order in their native language.

Our study suggests that individuals with DS might be engaging in strategies using frequency cues while learning and processing language-related information, which are also used by the TD populations. We thus identified a hitherto unknown strength of the DS population, which may support and facilitate language acquisition and learning. Considering these results, combining the knowledge of cognitive strengths in the domains that could be overlooked as weaknesses could be a strategy to approach a developmental milestone in a population that has specific challenges in language development (Chapman, 2006). These results represented a similarity in the acquisition and processing of the word order in DS and TD populations.

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