AN EPG ANALYSIS OF THE ARTICULATORY PATTERNS IN DOWN SYNDROME: A CASE STUDY

by

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ABSTRACT

Speech production in Down Syndrome is highly variable and inconsistent, characterized by severe pronunciation problems and low intelligibility. Although a number of different factors, such as physiological variations, phonological delay and motor constraints, have been described as possible causes of speech impairment in people with Down Syndrome, which of these factors are actually involved remains unclear.

The aim of the present thesis was to shed some light on the complex nature of speech impairment in Down Syndrome by examining electropalatographic data during the production of the Greek fricative consonants. Data was obtained from a Greek adult speaker with Down Syndrome. Normative data was obtained from a Greek adult speaker. Recordings were made while the participants produced a list of 149 words containing the fricative sounds of Greek both as singletons and clusters, in different environments and stress conditions. Electropalatographic analyses included examination of the total amount of linguopalatal contact, the center of gravity and the centrality measure for the fricative sounds. Factorial analyses of variance on the different measures were conducted, including subject, consonantal context, vowel environment, word position and stress assignment as factors.

After the collection of the electropalatographic data, the subjects were tested on a diadochokinetic task, which aimed to examine the speakers’ ability to alternate articulatory movements for the production of the target sound. The speakers repeated the syllables /pa/, /ta/, /ka/, as well as the sequences /ta_ka/ and /pa_ta_ka/ at a comfortable speech rate. Analysis of the diadochokinetic task included the number of syllables produced in a second.

The results of our research suggested differences in the amount of tongue-palate contact between the two speakers, with inadequate amount of tongue-palate contact (undershoot) for alveolar and palatal fricatives for the speaker with Down Syndrome. Undershoot was also a feature of clusters containing the fricative /s/. Significantly lower DDK rates were also observed in speaker DS. The results of the present thesis suggested that the articulation of speaker DS showed signs of both a dysarthric and a dyspraxic speech disorder and lends support to the theory that speech impairment in these individuals results from impairments at different processes required for speech production.
1. Introduction

Speech production in Down Syndrome (DS) is often described as variable and inconsistent, characterized by a high incidence of pronunciation errors (Hamilton, 1993, Timmins et al, 2007). Poor speech intelligibility is a typical pattern of their speech and remains one of the greatest barriers for effective communication (Bunton et al. 2007). Reviews on the speech impairment in DS have indicated a number of possible factors, including physiological variations with effects on the size of the oral tract, hypotonia of the muscles, phonological delay/disorder and motor programming deficits (Hamilton, 1993, Bunton et al., 2007). Intervention has been based on the existing linguistic theory, but low speech intelligibility still remains a problem for the majority of people with DS. Controversy on the type of speech impairment in this population and ineffective intervention strategies are likely to be attributed to lack of objective measurements for their speech characteristics.

The present thesis aims at shedding more light into the investigation of speech impairment in DS by using the technique of electropalatography (EPG), which provides a visual representation of tongue-palate contact during speech. The overwhelming majority of previous studies have mainly based their analyses on perceptual or acoustic data, which offered some important insight in the complex nature of speech production in DS, but were deprived of more objective data on the articulation patterns of people with DS. EPG is considered a more objective measurement tool and it has been used over the past 30 years to obtain information on the articulation patterns of both typical population and of people with speech problems (Hamilton, 1993). In our study, we will focus on the articulation patterns of fricative consonants by a Greek adult with DS and compare them with normative data obtained from a Greek adult participant. The target sounds include the Greek fricatives /s/, /z/, /h/, /y/ [ç] and [ʝ], as well as some selected Greek clusters with the fricative /s/, namely those belonging to one of the categories /s-stop/, /stop-s/, /s-stop-r/. For a complete description of articulatory placement, the target sounds were examined in different conditions according to word position, lexical stress and vocalic environment.

The scope of previous EPG studies on DS (Hamilton, 1993, Timmins et al., 2007, Cleland et al., 2010) is limited to the English language and has suggested a general lack of tongue postural control probably resulting from hypotonia, dysarthria (Hamilton, 1993, Timmins et al., 2007) or poor motor control (Cleland et al., 2010). To our knowledge,
there is no previous EPG study investigating the articulation of Greek people with DS and, more specifically, their speech patterns during the production of fricative sounds. However, due to the fact that differences were reported in relation to the English language, we might expect differences for the Greek language as well. We were interested in examining the patterns that the adult with DS would exhibit in his linguopalatal contact and if our findings would agree with previous studies with people with DS. In relation to clusters, we relied on the existing bibliography which indicated difficulties in the production of clusters due to uncoordinated speech and we were interested in the articulation patterns that speaker DS would exhibit during their production.

Our last research question concerned the performance of the two speakers in the Diadochokinetic task (DDK). Measuring DDK is considered a common assessment of oromotor skills and involves executing rapidly alternating movements for the repetition of syllables or sequences of syllables. Previous research has offered evidence of slower DDK rates for people with DS compared with TD, indicating motor constraints in the speech production of the former group (Hamilton, 1993, McCann & Wrench, 2007). Given results from previous studies, we also expected slower DDK rates for speaker DS than speaker TD.

2. Literature review

2.1. General characteristics of people with Down Syndrome

Affecting 1 in 800 newborns, Down Syndrome (DS) is nowadays considered a major cause of mental retardation (Korenberg et al, 1990). While in the neurologically typical population, the nucleus of the cells, where our genetic material is stored, contains 23 pairs of chromosomes, individuals with DS have an extra copy or a distal half of chromosome 21 (ndss.org). The presence of this extra chromosome leads to an additional dosage of genes, which in turn results to the abnormalities caused in the central nervous system of people with DS (Wisniewski & Silverman, 1996). These abnormalities are usually present during the late prenatal period and refer to decreased number of neurons, abnormal synaptogenesis and delayed brain development. DS occurs regardless of nationality, social status or sex (Kozma, 2008).

According to the National Down Syndrome Society (ndss.org), people with this genetic disorder belong to one of three different types of DS. The first type, ‘trisomy 21’, is the most common type, accounting approximately for 95% of the cases. People who
belong to this category usually exhibit the core features of the Syndrome, namely small bodily stature, low muscle tone and a slight slant to the eyes. The amount of chromosome 21 is the highest, as it is replicated in every cell of the body as the embryo develops. The second type, known as ‘translocation’, is found in about 4% of the cases and results from the attachment of chromosome 21 to another chromosome while ‘mosaicism’, the third and least common type of DS, results from the mixture of two different chromosomes, one containing the chromosome 21. According to Wisniewski et al. (1996), the degree to which this extra amount of chromosome 21 is found in the cells is strongly linked to the abnormalities caused in the central nervous system, and therefore results to different degrees of cognitive deficits. Indeed, people belonging to the third type of the Syndrome are said to have the fewest characteristics of those with the other two types. No certain conclusions can be drawn, though, due to the high variability of characteristics people with DS have.

Differences in the cognitive abilities of people with DS can be attributed to the comorbidity with other disorders that has usually been documented in some individuals. Buckley (2005) reported that about 5-7% of children with DS also exhibit autistic spectrum disorder (ASD). The reason why such a comorbidity often remains neglected lies in the fact that people with DS inherently have social skills that people with ASD lack. Due to the increased life expectancy that has been reported in the past few years, people with DS also suffer from premature aging and Alzheimer’s disease (Kozma, 2008). Most studies report an early onset of Alzheimer’s disease at the age of 50s. Apart from comorbidity with other disorders, people with DS usually exhibit a high incidence of primary congenital hypotheroism, congenital heart defects and leukemia (Fort, 1984, Desai, 1997, Freeman, 1998).

Several factors have been linked to the emergence of DS. In most cases, increased maternal age has been seen as the major cause of the syndrome (Mai et al., 2013). According to reports of the ndss.org., the likelihood of giving birth to a child with DS reaches 1/100 at the age of 40 in contrast to just 1/2000 at the age of 20. The age of the father can also play a role, but this only accounts for 5% of the cases. Apart from increased age, several other factors have been associated with the particular syndrome, such as alcohol, coffee or exposure to chemicals and pesticides (Hassold & Sherman, 2002). However, none of these factors has been proved to lead to the emergence of DS per se. Regarding the diagnosis, two types of tests are usually performed according to the ndss; prenatal screening tests, which only offer a probability and diagnostic tests, which provide a more accurate diagnosis.
2.2. The cognitive profile

Individuals with DS exhibit variable cognitive capacities, which are strongly linked with both genetic and environmental factors (Määttä et al., 2006). According to Rondal (1995), the modal IQ (intelligence quotient) in standard trisomy 21, ranges between 45 to 50 points. Rondal reports that the course of mental evolution in DS can be seen in three different stages: in the first stage, which concerns the first 4 or 5 years of chronological age, an individual with DS reaches a mental age of 18 months, while the two next stages lead to a mental development of 2-5 years up until the age of 15. The upper limit of mental development for DS is considered to be 5 years. However, a further but slower development may be seen in some cases. Manifestations of mental deficit that are strongly linked to the specific syndrome are limited efficiency in processing new information and retrieving already stored one, limited attention span, limitations in verbal short-term memory but a better preservation of visual-spatial short-term memory, slower reaction times and deficits in understanding mental states, namely in theory of mind tasks (Rondal 1995, Abbeduto et al., 2007, Gardiner et al., 2010).

In relation to their motor development, it has been shown that the order in which children with DS acquire some basic motor skills is the same as their typical developing (TD) peers, but differences are seen in the rate of acquisition (Vicari, 2006). More specifically, they start rolling between 5 and 6.4 months and they are able to sit independently between 8.5 and 11.7 months. Since TD children acquire independent sitting approximately in 6 months and rolling in about 4 months (Iverson, 2010), we observe that the acquisition of these motor skills is delayed. However, there is a greater delay in the development of subsequent motor skills. In contrast to their TD peers whose ability to crawl emerges between 6 and 10 months of age and walking is acquired approximately at 12 months (Iverson, 2010), children with DS acquire crawling between 12.2 and 17.3 months and walking between 15 and 74 months (Vicari, 2006). Apart from the qualitative differences, children with DS present some atypical body movements, such as sitting with legs extremely far away from each other or adopting a wide base walking frame. It seems, then, that their development is not only delayed, but it also exhibits signs of a disorder.

Interestingly, children and adults with DS often display greater difficulty with motor skills that demand speech and language processing than visuo-spatial skills. According to Bunn et al (2007), this can be attributed to the complex nature of processing
that is required when we perform a task involving speech. More specifically, the combination of the processing on the right hemisphere, which is responsible for speech perception and the processing on the left hemisphere, responsible for speech production, as well as the coordination of movements proves challenging for people with DS. Support for this theory has usually been offered by studies who tested individuals with DS on motor tasks and observed greater difficulty in tasks involving language processing than visual or spatial skills (Elliot and Weeks, 1993, Bunn et al, 2007).

In relation to language development, a general conclusion drawn from several studies is that DS is associated with greater levels of language impairment that any other form of mental retardation (Rondal, 1995). The language abilities of this population have also been reported to lag behind their cognitive skills (Caselli, 2008). Despite the variability found in each individual, the language skills in DS exhibit a similar pattern in different linguistic domains, with receptive skills being better preserved that expressive ones, a severe impairment in their morpho-syntax, a deficiency in relation to articulation and phonology and a better maintenance of their semantic and pragmatic knowledge, as well as their communicative skills (Buckley, 1993, Rondal & Comblain, 1996). This common pattern can be seen in an overview of the process of language development of children with DS.

To begin with, the onset of meaningful speech for children with DS is usually delayed in comparison with their TD peers (Rondal, 1995). The first meaningful words appear approximately between 24 and 30 months and a satisfactory proportion of word usage is rarely achieved by the age of 4, when more meaningful words are being used. Except for the delay in the onset of speech, the two groups do not display important differences in the acquisition of early vocabulary usage. Receptively, children with DS can comprehend as many words as TD children with the same mental age. The acquisition of early semantic relations is also delayed for children with DS, but not deviant (Rondal, 1995). According to Buckely (1993), the use of two-word phrases and short meaningful utterances begins once a child has established a vocabulary of about 50 words. Children with DS express the same relational meanings as TD children and, generally, make use of correct semantic structures (Rondal, 1995). Of particular interest is also the increase in vocabulary comprehension around adolescence (Chapman, 2006). However, it is still unclear whether this development reflects a characteristic of the specific syndrome or if it is connected with increased life expectancy, as increased chronological age has been connected with gains in vocabulary skills in the mentally retarded population (Facon, Facon-Bollengier & Grubar, 2002).
The difference in the development of receptive and expressive language skills is a controversial issue. Mundy et al. (1995) supported that the expressive language delays that characterize the speech of people with DS might be linked with an earlier disturbance in the development of nonverbal requests. Such a connection would lead us to the conclusion that the expressive language delays cannot be explained only in relation to subsequent language development, but should also be associated with delays in an earlier phase of nonverbal communication. Indeed, the children tested in this longitudinal study presented with disturbances in nonverbal requests and, subsequently, with delay in the development of expressive language.

Reading skills in DS is a rather vague area, with some researchers supporting a profound difficulty due to lack of phonological awareness and some others indicating the adaption of other techniques during the reading process (Roch & Jarrold, 2008). Phonological awareness refers to a speaker’s ability to comprehend and manipulate the speech sounds of a language and is usually measured by means of syllable or letter identification, spelling and nonword production. Cupples and Iacono (2000) examined how the level of phonological awareness of 22 children with DS correlated with the acquisition of oral reading skills and found that children with better reading abilities were also better at tasks relating to their phonological awareness, such as segmenting words and nonwords into their constituent phonemes. However, lack of phonological awareness does not necessarily mean that people with DS are incapable of developing reading skills. In Roch and Jarrold’s (2008) study of 12 adolescents with DS, participants seemed to rely on visual rather than phonological information of the word in order to successfully produce it and did not present significant impairment in their reading skills compared to an age-matched TD group, who scored higher on tasks relating to phonological awareness. This led Roch and Jarrold to conclude that children with DS may acquire reading skills in a different way than TD children.

Morpho-syntax is the level of language that is most impaired in this population (Rondal, 1995). Although some progress can be observed with increased age, their grammatical development is never entirely complete. In Rondal’s (1995, p.9) words, the ‘spontaneous combinatorial language of individuals with DS remains largely telegraphic’, characterized by a limited use of function words and inappropriate feature marking especially on pronouns and anaphors. Subjects with DS usually pertain to simple and short utterances in order to maintain correct word order. The fact that these difficulties cannot be overcome later in adolescence may prove that DS may particularly affect the grammar and syntax of the language, with individuals never being able to exceed a certain level of
development (Fowler, 1990). Several authors have observed that some deficits in the morphological area cannot be attributed to the cognitive deficits of this population, though, and suggested that problems that are often found in their perception and articulation may lead them to the construction of atypical morphophonological representations (Caselli, 2008). In contrast to morpho-syntax, the use of pragmatic features does not seem impaired in DS. Jonston and Stansfield (1997) compared the pragmatic skills of 6 children with DS and 6 TD relying on their parents’ report of their children’s typical communication skills (e.g. rejecting, commenting or requesting). The results of the study proved that the pragmatic skills of children with DS were not impaired in comparison to the TD group. However, a few studies have reported delayed pragmatic development, with difficulties arising mainly in relation to requests (Abbeduto et al., 2007). The research regarding the pragmatic skills of children with DS is limited, relying mainly on parent’s reports; however, strengths in pragmatic skills have been linked to gains in later language development.

2.3. Speech production in Down Syndrome

Speech production in Down Syndrome is usually associated with poor articulation and low intelligibility. According to Hamilton (1993), speakers with DS exhibit a higher incidence of speech problems than any other group of people with learning difficulties. Kumin (1994) also reported that over 95% of parents with children with DS found their children’s speech difficult to understand, especially in unfamiliar settings. Although some improvement can be observed with increased age, reduced speech intelligibility remains a problem even for subjects with more advanced syntax, such as adults or older children. Impaired production of speech sounds, atypical prosody and fluency disorders are some of the patterns that seem to characterize their speech production (Bunton et al., 2007). Many reasons have been proposed for the speech difficulties of these people, with an increasing body of research suggesting that they result from impairments in all the different components necessary for successful speech production, namely in their ability to carry out the movements of the speech organs (articulatory), select the appropriate sounds (phonological) and execute the appropriate movements for their production (motor programming) (Hamilton, 1993). However, which of the factors proposed are really involved remains unclear.

Individuals with Down Syndrome are characterized by a unique anatomical structure, which may have an impact on their speech production. The most common
features are the relatively small size of the oral cavity, a high-arched palate and a large tongue, weak facial muscles and reduced bone growth of their face and head, limited lip movement and differences in their vocal folds (Stoel-Gammon, 1997, Bunton & Leddy, 2011). The large tongue and the high palate arch relative to the size of the oral cavity may interfere with correct articulatory placement. The weak facial muscles and the limited lip movement negatively affect the production of speech sounds, such as labial consonants and rounded vowels (Stoel-Gimmon, 1997), while abnormalities in both their oral and pharyngeal cavities influence their voice quality and, subsequently, the acoustic characteristics of their speech. Their muscles and tongue suffer from hypotonia, a feature that is seen as a sign of dysarthric speech (Hamilton, 1993).

Another factor that has usually been associated with speech and language deficits in DS is the high incidence of hearing problems. Research in hearing loss indicated a prevalence of 38% to 78% in this population, as opposed to 9% found in the population with some other form of mental retardation (Roizen et al., 1993). Downs (1980) reported that 78% of the children with DS she tested were found to have hearing problems in one or both ears with 15 dB being the lower threshold. Factors that are associated with the incidence of hearing loss in this population include stenotic ear canals, a small nasopharynx and adenoid and tonsil hypertony (Roizen et al., 1993). Reduced hearing abilities might have an adverse effect on language development, since an important part of the language we acquire is based on the auditory input we receive (Saffran, 2002). Inadequate understanding of the phonological input may lead to weak auditory memories or even erroneous representations of the phonological form of a word (Arias-Trejo & Barrón-Martínez, 2017). However, the connection between hearing deficits and language abilities has also been rejected (Trejo & Barrón-Martínez, 2017). Chapman et al (1998) for example, reported that a very small number of the language deficits of people with DS could be attributed to hearing loss, while Laws and Gunn (2004) found no relationship between the auditory skills of people with DS and the number of words each person produced in a sentence (commonly cited as the MLU score). The investigation of whether hearing impairment is an important factor of speech and language problems in DS is quite difficult due to the fact that individuals with low hearing levels are typically excluded from studies.

In addition to the above mentioned physiological differences, the poor performance that individuals with DS have at different levels of motor functioning and, especially, speech motor control has usually been seen as another important reason for their problems (Bunton & Leddy, 2011). According to Kent (2000, p. 391) “speech motor control refers
to the systems and strategies that control the production of speech”, where the input is the phonological representation of a language and the output the execution of the necessary articulatory movements for the production of speech. Research points out to the fact that these people face difficulties in speech motor skills and motor planning, namely in their ability to execute the appropriate movements for speech and to combine sounds into meaningful words and phrases. Barnes et al. (2006) reported that boys with DS showed significantly slower tongue and lip movements than their age-matched TD peers, as well as less coordinated speech patterns than boys with fragile-X. Kumin (2006) found that the majority of children with DS show signs of childhood apraxia of speech, a disorder which is characterized by the inability to volitionally plan, program and direct movements for intelligible speech (ASHA, 2007). However, only a minority is actually diagnosed with the specific disorder. It is clear that these difficulties, if present, may affect their speech to a great extent. The assumption that poor speech intelligibility can be attributed to impairments in the speech motor control system initially received minimal support, but, nowadays, evidence that these two can be related continues to grow (Bunton et al., 2007).

Rupela et al. (2016) supported that the speech impairment in DS is consistent with motor impairment, but the nature of this impairment is still not clear. The existing literature points out to the fact that the speech characteristics that are usually encountered in people with DS reflect both symptoms of apraxia of speech and dysarthria. This was also found in their comparison of motor skills of children with DS and typically-developing children. Results obtained from a number of speech motor control tasks, involving DDK, indicated that children with DS had a mixed profile. Within the symptoms of apraxia of speech, Rupela et al. (2016) reported difficulties with the execution of speech movements (manifested as groping), decreased accuracy and rate in DDK tasks, as well as inconsistent repetition of words. On the other hand, hypotonia, which lead to limited movements of the lips and the tongue and deviant voice and pitch were seen as a sign of dysarthric speech. Regardless its nature, the researchers adhered to the assumption that motor constraints are responsible for speech impairment in DS.

Additional evidence that poor motor control may be responsible for the speech of people with DS is based on the high incidence of disfluencies that is usually observed in their speech. When examining the TD population, the term ‘disfluency’ commonly describes the speech that is characterized by repetitions, interjections and pauses and contrasts to the rhythmical flow of speech (Gillam, 2000). Disfluencies mainly occur in spontaneous speech and have a direct impact on various phonetic aspects, such as
duration, intonation, voice quality and coarticulation (Shriberg, 1999). Some examples of disfluencies are blockages (silent tense prolongations before the onset of sounds) repetitions (of whole word or part of word), prolongations (excessive stretching of a sound). In cases where such disfluencies are observed in an unusual number and interfere with the speaker’s ability to communicate effectively, we have a condition called ‘stuttering’ (Gillam, 2000, p.315). Blockages are considered among the core characteristics of stuttering and indicate the person’s inability to control the tension necessary for the production of a certain sound due too excessive intrinsic pressure (Campbell and Hill 1987, Guitar 1998). Although the origin of stuttering is still a controversial topic, many researchers consider it to be mainly a speech motor disorder due to the fact that people who stutter seem to face difficulties with controlling the speech organs as well as the air inhalation and exhalation they need for speaking.

Regarding the DS population, Willcox (1988) reported that the incidence of stuttering (which varies from 15% to 60%) is higher in comparison with any other group of mentally disordered people. However, a question that concerns the existing literature to date, is whether the nature of the speech disfluency observed in DS should be described as stuttering or ‘cluttering’ (Willcox,1988, p.154). The line between stuttering and cluttering is difficult to delineate, with some researchers supporting that a person who stutters employs some avoidance techniques in order to maintain a normal flow of speech (Willcox, 1988), while a person who clutters is not aware of his or her speech disfluencies. Preus (1996) explained, though, that cluttering is more extensive than stuttering and should not be classified as a purely fluency disorder, due to the problems that seem to exist also at an articulatory and language level. A more recent description by Ward (2018) defines cluttering as rapid language, accompanied with excessive articulation and an abnormal number of pauses.

Eggers and Van Eerdenbrugh (2018) examined the speech disfluencies that occurred in the spontaneous speech of 26 children with DS, with an upper age of 13 years. The data was obtained while children performed two different tasks that encouraged spontaneous speech. The results of this study suggested that, although speech disfluencies occurred in 30% of the children, none of them could be classified as solely a stutterer or a clutterer due to the high variability of the disfluency patterns. For example, a big number of children exhibited prolongations and repetitions of syllables or parts of the word, which are considered to be among the core features of stuttering. Surprisingly though, the most frequent type of speech disfluency was not repetition (as typically occurs in people who stutter) but blockages. In relation to features related to cluttering, Eggers and Van
Eerdenbrugh mentioned that, although some participants demonstrated characteristics that are typical of cluttering, such as increased speech rate and long pauses, there was no consistency in the number and type even within the same person, as each participant exhibited different features and amount of cluttering in the different tasks. These findings might suggest that the nature of speech disfluency in DS is different to that of stuttering.

A similar question regarding stuttering in the DS population is whether people with DS who stutter have different motor abilities from fluent speakers with DS. Devenny et al. (1990) conducted a research to examine the performance of one group of people with DS characterized as stutterers and one group characterized as fluent speakers on speech and manual motor tasks. The tasks were also divided according to complexity. The results of the study showed that stutterers with DS were faster than fluent speakers on simple repetitive tasks (such as the DDK task, which tested their speech motor control), but slower on tasks with more demanding motor movements. The different performance of the two groups led Devenny et al (1990) to the conclusion that people with DS who stutter have a different motor organization than fluent speakers with DS. This observation also has important implications for the speech characteristics of people with DS and may account for the high variability that is observed in the speech of this population.

The issue of whether the speech of people with DS reflects patterns of a delay or a disorder remains debatable up to date. Research focusing on this question has yielded controversial results. Bleile and Scwarz (1984) recorded the spontaneous speech of 3 children with DS over a period of 12 weeks. Their findings revealed that children with DS committed errors typically observed at children of a younger age, listing deletion of final consonant, stopping and cluster reduction among the most usual processes. They also observed many errors related to voicing, as one of the children usually alternated between the voiced and the voiceless velar for the target /g/, one of them had no voicing opposition between the velar stops and the last child seemed to lack voicing opposition for the majority of the phonemes. More recently, Stoel-Gammon (2001) also supported that the phonological development of children with DS is only delayed in comparison to TD children, as the acquisition of sounds follows a common path. Specifically, both groups first produce accurately stops, nasals and glides, while fricatives, affricates and liquids are mastered later. Similarities are also found in their errors, with the production of consonant clusters as singletons, the omission of word final consonants and the deaspiration of word-initial aspirated voiceless stops being among the most common phonological processes observed in both children with DS and TD. However, Martin et al. (2009) observed the inconsistency of errors that has usually been reported in the speech
of children with DS, as well as their pervasiveness through longer periods of time, indicating that their speech development exhibits characteristics of a disorder. The same opinion was also shared by Dodd and Thompson (2001), who compared the inconsistency in within-word errors between children with DS and children with speech disorders and found no significant difference on their performance.

At this point it should be noted that the speech errors of people with DS, as well as the low intelligibility, have often been associated with prosodic deficits or voice characteristics (Stojanovik, 2009). Even though the successful use of prosody is an important component of effective communication, only few studies have examined possible impairments in the prosody of people with DS that may also explain why their speech is often characterized as unintelligible. Problems related to both comprehension and production of prosody were reported in Stojanovik (2009), who compared prosodic use in children with DS and a group of age-matched peers. The results of her study indicated that children with DS do not process or use prosodic features as effectively as children at the same chronological age. Children with DS scored lower in tasks asking them to discriminate between different intonation patterns or marking with stress the most prominent word in an utterance. In general, they were better at understanding than producing correct prosodic utterances, an observation that is line with the fact that receptive language abilities are better preserved than expressive ones (Buckley, 1993, Rondal & Comblain, 1996). Similar observations were also made by Pettinato and Verhoeven (2009), who examined stress perception and production in children and adolescents with DS and found difficulties in the correct processing of stress while performing the tasks. According to the researchers, insufficient stress processing might be responsible for the low intelligibility which characterizes people with the certain syndrome.

Regarding their voice quality, characteristics such as excessive roughness, breathiness, nasality and a low pitch have usually been related to DS. As Moura et al. (2008) explained, problems related to the voice of mentally disordered people may be responsible for decrease in speech intelligibility. In their study, the vocal quality of 66 Portuguese children with DS was compared to that of an age-matched group. The results suggested a generally unstable voice with a profound loss of control of vocal fold tension. \( F_0 \) was lower and analysis of \( F_1 \) and \( F_2 \) suggested loss of distinction among the vowels, a feature confirmed both by acoustic and perceptual analyses. Albertini et al. (2010) provided conflicting results in their study of the voice characteristics of children and adults with DS. More specifically, children with DS did not present higher or lower levels
of \( F_0 \) when compared to the TD group, while their voice was not characterized by excessive jitter of shimmer as supported by previous research. However, significant differences were found between the adults with DS and their age-matched control group, as the former exhibited higher \( F_0 \) values and lower levels of energy. Research on phonation and intonation remains up to date limited, characterized by a small sample and lack of objective measurements (Albertini et al., 2010).

2.4. Previous experimental studies on speech production

The speech characteristics of people with DS have been examined in several studies, which tried to shed light on the nature of their low speech intelligibility. Roberts et al. (2005) compared the speech patterns and the phonological processes employed by three different groups with English children, 50 boys with fragile X, 32 boys with DS and 33 age-matched TD. Their production was assessed based on their single-word responses to stimulus pictures of a standardized articulation task, which tests the speaker’s ability to produce all the English consonants in initial, medial and final position. The results of their study proved that, whereas the boys with fragile X exhibited only delayed speech development in comparison to younger mentally-aged matched TD, the boys with DS displayed patterns of sound change that match not only a delayed, but also a disordered speech development. More specifically, they committed errors even on the early-developing sounds (namely stops, nasals and glides) and they were able to accurately produce only few of the late-developing sounds (fricatives, affricates and liquids). Cluster reduction was the most usual phonological process, while final consonant deletion and lateralization of sibilants were also observed in some speakers. The participants also tended to omit entire syllables, which might have contributed to the low speech intelligibility of the speakers with DS.

Borsel (1996) examined whether the articulatory problems of adults with DS reflect a delay in speech development. For this purpose, the speech errors of 20 adults with a mean mental age of 5;8 were compared to those of 20 toddlers with a mean age of 3. The subjects were shown a series of pictures and were asked to name common objects and actions. The analysis concerned the production of consonants, vowels and diphthongs. The results showed that there were many similarities in the performance of the two groups, as both of them committed an almost equal number of errors, mispronounced mainly fricatives and more consonants in clusters than as singletons and
made distortions of sounds more frequently than any other error type. For vowels and diphthongs, the overall error rate did not vary significantly. The results from this study led Borsel to the conclusion that the speech development of people with DS should be characterized as delayed.

Bunton et al. (2007) carried out an experiment in an effort to explain which speech errors underlie the speech intelligibility deficit of five English adults with DS aged 26-39 years old. The participants were tested on the production of 53 words containing sounds that are considered to be problematic for people with speech motor disorders. Their analysis concerned the phonological processes observed in the speech sample of the participants. According to ASHA, some common phonological processes encountered in pathological speech include fronting (for example when a velar sound is replaced by an alveolar sound), stopping (a fricative or affricate sound is replaced by a stop sound), deaffrication (an affricate is replaced with a fricative), cluster reduction (a consonant cluster is reduced into a single consonant) and final consonant deletion. The results of Bunton et al. suggested that simplification of clusters, both at word initial and final position, vowel errors and place of articulation for stops and fricatives were the most common phonological processes observed among the five speakers. As Bunton et al. (2007) explained, the difficulty in distinguishing among high/low and front/back vowels and to accurately produce stops and fricatives probably results from poor lingual posture and control, while cluster simplification is a result of uncoordinated speech. The fact that these errors were mostly observed in the participants’ speech brought proof that low intelligibility of people with DS is a result of a speech motor disorder.

The production of vowels has also been examined in the study of Bunton and Leddy (2011), who tested the four English corner vowels by two adults with DS and two age-matched English speakers. The aim of the study was to test whether acoustic vowel space area and articulatory working space were compressed in speakers with DS in comparison to the control group, as these two measures are believed to affect vowel articulation and correlate with overall speech intelligibility. Their findings suggested that the acoustic vowel space area of speakers with DS was relatively compressed in comparison to that of the control group and explained that this may be responsible for the reduced acoustic contrast among vowels that speakers with DS usually exhibit. Apart from constraints imposed by physiological factors, Bunton and Leddy observed that speakers with DS were slower in the execution of articulatory movements in comparison to the control group. This observation indicated motor constraints which, in combination to the anatomical variations, influence an individual’s precision in speech production.
More objective data on the articulatory patterns of people with DS was offered by researchers who made use of Electropalatography (EPG). Hamilton (1993) compared tongue movements and diadochokinetic (DDK) rates of three English adults with DS and one neurologically age-matched adult. The participants’ production was examined in three different conditions: imitation of spoken words, words presented as pictures and in written form. The EPG frames of all speakers with DS revealed great amount of palatal contact for alveolar stops /t, d, n/, more palatal and velar contact for the lateral /l/, incomplete tongue-palate contact for velars /k, g/ and increased palatal zone contact for fricatives /s/ and /ʃ/, which were also difficult to distinguish auditorily. Consonant clusters were also produced incorrectly, as, instead of coarticulation, insertions and omissions of given sounds were mainly used by the three speakers. Apart from these, the adults with DS produced slower and arrhythmic DDK rates, with the sequence /p-t-k/ being the most challenging for all of them. According to Hamilton (1993), her findings lend support to two factors affecting articulatory patterns in DS. Firstly, the overshoot observed in fricative sounds, the lack of auditorily discrimination between them, as well as the lack of overlapping articulation in consonant clusters point to dysarthric speech, as they indicate the speaker’s inability to move the tongue accurately to different places on the palate, which has been proven difficult for tongues with hypotonia (Hardcastle, 1985). Secondly, the difficulty in repeating consonant-vowel sequences in DDK indicate motor sequencing problems. The findings from her study imply that people with DS face difficulties in both moving the speech organs to articulate speech and in accurately sequencing the appropriate sounds.

In a case study by Gibbon et al. (2003), EPG was used to diagnose and treat velar fronting in a 10-year-old girl with DS. The subject’s articulation was tested using a standardized test and the EPG patterns showed alveolar placement /t, d, n/ for the velar targets /k, g, ŋ/ in all phonetic contexts. Fronting was also observed in fricatives /ʃ/ and /ʒ/ as well as affricates /tʃ/and /dʒ/ in many cases. Among the most common phonological processes were devoicing of final voiced consonants and cluster reduction. Apart from the utility of EPG in the assessment of speech problems, Gibbon et al. (2003) also highlighted the contribution of the specific tool in the treatment of speech errors, as the girl with DS exhibited improvement in velar fronting after a 14-week treatment with visual feedback.

More recently, Timmins et al. (2007) used EPG to examine the production of the English fricatives /s/ and /ʃ/ in six young people with DS and compared the variability of the productions with a standardized measure for speech motor control. The subjects were
first asked to read a list of 10 words containing the target sounds and then they were tested on a motor control test. The EPG analysis showed significant differences in palate contact for the production of the two target sounds. For the fricative /s/, two of the speakers with DS exhibited patterns similar to TD, while three of them showed a grooved pattern, resulting in more velar contact and the perception of /s/ as /x/ in one of the speakers. Only one speaker exhibited complete closure for /s/ sound. In relation to /ʃ/, results were also variable, as only one speaker managed to produce /s/ accurately, three speakers produced /ʃ/ as /s/ and one speaker showed complete contact at the anterior place of the palate. The analysis of the scores in the motor control test showed that production of fricatives and performance on the speech motor task correlated significantly. Specifically, the two speakers who exhibited the most variability in the production of the fricatives also scored lower in the motor control test, while those who scored higher in the oral motor task had less variable patterns in comparison with the rest of the speakers. According to Timmins et al. (2007), the correlation found between the impaired speech production and poor motor control seems to support the theory that the speech motor control of people with DS might be responsible for their deviant articulation.

In a subsequent study, Timmins et al. (2008) examined the coarticulatory patterns of six children with DS aged 9-15 years using EPG. Their aim was to investigate whether children with DS manifested abnormal patterns of coarticulation due to uncoordinated speech articulators. The participants were asked to read a list containing the phrases ‘a clock’ and ‘a red car’ in order to test temporal and spatial overlap in the /kl/ and /d#k/ sequences. The results of this study yielded controversial results. Speakers with DS exhibited motoric deficits in the /kl/ sequence, as they were unable to synchronize the alveolar gesture for the sound /l/ with the velar gesture for the /k/ sound. According to Timmins et al. (2008), the subjects’ performance on the specific task was compatible with the performance that speakers with Childhood Apraxia of Speech (CAS) have exhibited in previous studies regarding coarticulation in this population. However, full assimilation was observed in the /d#k/ sequence, a finding that was unexpected for speakers who experience speech motor deficits. The researchers attributed this difference in performance to the fact that assimilating the /d/ sound in a velar is motorically less demanding than the production of the /kl/ sequence.

EPG was also used in the experiment by Cleland et al. (2010), whose aim was to examine whether the severity of speech disorders of 15 English children and adolescents with DS aged 9-18 years correlated with their language, cognitive and oromotor skills. For this analysis, the participants were tested on a number of standardized tests. For the
analysis of the speech production, they were tested on a standardized phonological test while wearing EPG palates. A test that addressed their speech intelligibility was also administered. The results showed that consonant cluster reduction was the most common phonological process, with final consonant deletion and gliding coming next. One interesting finding from their study was that the performance of the subjects in the phonological test correlated significantly with their scores at the oromotor function test, as subjects who performed worse at these tasks also had the lowest score in speech intelligibility and they committed the most errors. No correlation was, though, found between the phonological test and their language and cognitive measures. The findings from Cleland’s et al. (2010) study support that low speech intelligibility in DS may be a result of their poor speech motor control.

3. Methodology
3.1. Research questions

The main aim of the present thesis is the description of the articulatory patterns of a Greek adult with DS using EPG, and the comparison of his linguopalatal contact with a normal speaker. In this study, fricatives were chosen for examination. The precise articulatory and aerodynamic control that is necessary for the production of fricative sounds makes them a very interesting category for analysis. We thus aimed at analyzing fricatives both as singletons and in clusters, in word initial and middle position, followed by three different vowel environments.

To our knowledge, there is no previous EPG study examining tongue-palate contact for Greek speakers with DS. The only evidence comes from English studies (Hamilton, 1993, Timmins et al, 2007) which examined fricatives /s/ and /ʃ/ and reported diverse EPG patterns for speakers with DS. In the present study, data is obtained from an adult speaker, whose speech was characterized by a considerable number of disfluencies. It should also be noted that the subject has undergone partial glossectomy at an early age. Taken all these into consideration, we were interested in finding what differences the two Greek speakers of our study would exhibit in their EPG patterns and if the contact patterns of the speaker with DS would resemble those found in previous EPG studies.

In order to further examine the tongue movements and the speech control of the adult with DS, we employed Diadochokinetic rate techniques (DDK). In this task, we were interested to examine whether the speaker with DS would produce slower and more
arrhythmic DDK rates in comparison with the Greek speaker. The findings from the EPG and the DDK analysis are expected to lend some support some of the existing theories regarding the speech problems and the low intelligibility of people with DS.

3.2. Participants

EPG patterns of a Greek adult with DS, speaker MB, were compared to normative data from a Greek adult speaker, speaker KK. The two subjects were of similar age, 32 and 35 years old respectively. Both of them were selected on the basis of living in Thessaloniki and speaking Standard Greek, in order to avoid differences based on dialect variation. Subject KK was a teacher of Greek who agreed to take part in our study.

Speaker MB attended an educational association for people with special needs at the time of his recruitment. According to his parents’ reports, he spent his school years at state schools in Thessaloniki. As a child, he also visited a speech therapist for about 3 years. The subject’s treatment was not consistent from then on, as the subject visited the speech pathologist of the educational association only a few times. We should also mention that speaker MB underwent partial glossectomy at a young age, as the majority of people with DS who have macroglossia (Stoel-Gammon, 1997).

Another important factor that we had to take into consideration was the fact that our speaker should have been diagnosed only with ‘trisomy 21’ and with no other comorbid form of mental retardation, such as autistic spectrum disorder. Apart from that, he should not suffer from severe hearing loss and have adequate comprehension in order to be able to follow our instructions. However, it became apparent that the subject’s speech was characterized by a considerable number of disfluencies. As already mentioned, fluency problems such as stuttering or the so-called ‘cluttering’ are common for people with DS (Willcox, 1998, Eggers & Van Eerdenbrugh, 2018). Speaker MB had not received a diagnosis for stuttering, but it was apparent that his normal flow of speech was interrupted mainly by blockages and syllable repetitions.

Speech, language and hearing tests were carried out on MB. For the evaluation of speaker’s MB speech, we administered the Phonological Test of the Panhellenic Association of Logopedics (1995). In this test, the subject is evaluated on his/her ability to pronounce the target word that is displayed on a picture. The target words include all the consonants and vowels of the Greek language, found in different contexts. For descriptive purposes, we calculated the Percentage Consonant Correct (PCC) index, which shows the percentage of the target consonants that were articulated correctly by the speaker and
indicates the degree of speech impairment (Shriberg et al., 1997). The calculation of PCC suggested a moderate degree of severity for our participant, since 80% of intended consonants were pronounced correctly (Zanichelli & Gil, 2011).

Due to the hearing difficulties that are often encountered in the specific population, the subject was asked to visit an otolaryngologist, who assessed his hearing skills by means of audiometry and concluded that the person had normal hearing levels (30dB). People with DS also present with deficits in verbal short-term memory (Jarrold & Baddeley, 2001). A common measure of this ability is the digit- or word-span test, in which participants are asked to repeat an increasing number of verbal items in the correct order. For the present study, the digit span (both digits forward and digits backward) was administered to speaker MB. Cumulative score amounted to 6 (score of digit forward=4, score of digit backward=2), which is considered a common verbal short-term memory span for individuals with DS (Jarrold, Baddeley, & Phillips, 2002).

3.3. Materials

In the present study 149 target words were used to provide data for analysis. The list mainly consisted of bisyllabic words, but trisyllabic words were also used for some fricative consonants. All consonants were tested in four different conditions, word-initial/stressed, word-initial/unstressed, word-medial/stressed and word-medial/unstressed, followed by three different vowel contexts /i/, /a/ and /u/. For singletons, all words had a CVCV structure where, according to the condition under examination, C represented one of the Greek fricatives /s/, /z/, /x/, /ɣ/, /ç/ or /ʝ/ and V one of the afore mentioned Greek vowels. In should be noted that, wherever possible, the same vowel was used in both V places. Some examples of the words used for singletons are /'sima/, /'zari/, /'ɣuri/(word-initial/stressed), /xa'ra/, /si'ra/, /'ɣu'di/(word-medial/stressed), /pa'sa/, /si'ɣi/, /pa'çi/ (word-initial/unstressed), /'ziɣi/, /'vraça/, /'θasu/(word-medial/unstressed).

One thing should be noted in relation to the singletons studied in the present study. In Greek, we have a phenomenon called palatalization, which refers to the change of the consonants /x/ and /ɣ/ from velar to palatal in the context of the vowel /i/ or when another vowel occurs with /i/ in the same syllable (Joseph & Philippaki-Warburton, 1987). The phenomenon of palatalization is observed in many consonants of the Greek language, but here we refer to the fricatives that are the target of our study. Since /x/ in the environment of /i/ changes into its regular allophone [ç] and /ɣ/ into [j], these two palatal sounds were
studied only when found in the specific vocalic environment or when another vowel was found with /i/ in the same syllable.

Apart from singletons, the fricative sounds were also analyzed as part of a cluster. The list consisted of clusters with the fricative /s/ and one of the stops /p/, /t/ and /k/ preceding or following the target fricative sound. The clusters under examination were /sp/, /st/, /sk/, /ps/, /ts/ and /ks/. The fricative sound was also tested in /s-stop-r/ clusters, namely in the context of the consonant clusters /spr/, /str/ and /skr/. The exact same principles applied for the words containing the clusters, so that they were also tested in four different conditions: word-initial/stressed, word-initial/unstressed, word-medial/stressed and word-medial/unstressed (some examples are /tsili/, /ksi'nii/, /aspri/). Both in singletons and in clusters, each word was preceded by a definite or indefinite Greek article. In order to avoid effects of the preceding vowel, we tried to use the article that ended in the same vowel as the one found in the first syllable of the target word, for example /mia 'saka/ (word-initial/stressed condition, /i j'i ni/ (word-initial/unstressed condition). Each item was repeated 5 times by the two subjects. The whole list of words used for the study is included in the Appendix.

In the DDK task, the speakers were first asked to repeat the syllables /pa/, /ta/, /ka/, which represent three different places of articulation and, therefore, allow us to examine the movement of different articulatory muscles (Devenny et al.,1990). The speakers were also asked to repeat the sequences /ta_ka/ and /pa_ta_ka/ which examine the accurate repetition of alternating sounds. The choice of the same vowel is made in order to control the environmental effect. DDK rates were measures by counting the number of syllables each participant produced per second.

3.4. Procedures

Speakers MB and KK visited a dentist to have their dental casts made. Both casts were constructed at the School of Dentistry of Aristotle University of Thessaloniki. EPG palates were manufactured by Articulate Instrument. Once the participants received their palates, they were asked to wear them for increasing periods per day in the week before the recordings and report whether the palate impeded their articulation. Apart from that, they were asked to wear them each time for at least ten minutes before the data collection. We wanted to ensure that the palates did not affect the subjects’ articulation as much as possible.
The subjects visited the Phonetics Laboratory for the data collection. One important factor that we took into consideration was the way the words would be presented to our participants and, especially, to MB, so that his speech was as fluent as possible. The target words were presented in pictures with an acoustic trigger. For each word, the participant had to listen to the recorded material and then repeat the word, which was also displayed in a screen. For example, for the word /'supa/, the subjects were shown a picture with a bowl of soup and listened to the recorded phrase /'mia 'supa/. The subjects’ response was delayed, as they had to repeat the phrase with the researcher’s signal. It should be noted that the researcher did not intervene in the procedure and word repetition was only used when a word did not match the intended target, not when a distortion occurred (for example speaker MB once produced the Greek word /ta'yari/ as [pa'yari] because he was not aware of the meaning of the word and asked for a clarification). This method proved the easiest for MB to follow. EPG patterns for the items were stored for analysis.

3.5. Data recordings and analysis

3.5.1. EPG data

Acoustic and EPG data were simultaneously recorded using the Articulate palate by Articulate Instruments. The artificial palates have 62 electrodes on their surface, which are distributed in eight rows. The first row corresponds to the dental region and the second to the alveolar zone. Rows 3 and 4 correspond to postalveolar regions, while the palatal zone is subdivided in palatal (rows 5, 6 and 7) and velar regions (row 8) (Wrench, 2007). The electrodes are also distributed in eight columns: the first two columns on the left and right side of the palate are characterized as lateral, while the four found in the central region of the palate are described as central (Gibbon & Nicolaïdis, 1999).

Measurements of the duration of the fricative sounds were based on the acoustic analysis, for which we used the Praat speech analysis program (Boersma & Weenink, 2005). Segmentation in Praat was then imported in the EPG software. Onset was identified at the beginning of friction for each consonant and offset at the end of it. The EPG frame for each target sound was calculated from the midpoint of all frames in the annotated region. EPG data analysis concerned the calculation of the following measurements:

a) totals measures
b) the centre of gravity (COG)
c) the centrality index and, more specifically, the front centrality index for contact at the front four rows and the back centrality index for contact at the back four rows of the palate.

Totals measure is an index used for specifying the amount of tongue-palate contact. In the present study, three different measures of total amount of contact were used. Whole total showed the amount of contact on the entire palate and was used when the two speakers exhibited important differences in place of articulation and contact did not occur in the expected zone. Alveolar total showed the amount of contact occurring at the alveolar zone of the palate (namely in the front four rows) and was therefore used for alveolar fricatives, while velar total concerned the amount of contact occurring at the palatal zone (namely in the back four rows of the palate) and was used for palatal and velar fricatives.

The COG is an index of the main concentration of activated electrodes in the palate. The calculation assigns progressively higher values to the electrodes found at the anterior rows of the palate (Gibbon & Nicolaidis, 1999). Measurements of the COG were made across all rows of the palate. The mean central measure was used in order to see whether there was more contact near the midline or the lateral sides of the palate. Front centrality was selected for the fricatives whose place of articulation was expected to take place in the alveolar zone. Back centrality was selected for consonants whose place of articulation commonly occurs at the palatal zone. Factorial analyses of variance on the different measures were conducted including word position, stress and vowel context as factors. All main effects and interactions were examined.

3.5.2. DDK rates

In our second task, the subjects were asked to produce the syllables and the sequences of the syllables at a comfortable speech rate in the provided timeframe. In order to elicit enough data, each DDK task was repeated three times.

4. Results

4.1. EPG results for the production of fricatives as singletons

4.1.1. Results for alveolar place of articulation
Figure 1 displays EPG palatograms for the fricative /s/ in the environment of /i/, /a/ and /u/, first in word-initial, stressed/unstressed position and then in word-medial, stressed/unstressed position. Figure 2 shows palatograms for the fricative /z/ in the same environments for the 2 speakers. Percentage of contact over five repetitions is evident on the palatograms for all target words. The most striking finding is the difference between the two speakers in place of articulation for both target sounds. For speaker KK, place of articulation is consistently found on the first three rows, corresponding to the alveolar place of articulation for the Greek fricatives /s/ and /z/. For speaker MB, there is a very open pattern anteriorly and constriction seems to occur posteriorly at the last rows of the palate (for example see /suˈsu/, where constriction is evident in rows 7 and 8). Only in /suˈja/ we have some evidence of constriction in the third row, but again posterior constriction is also evident. For /z/, place of articulation for speaker MB seems again more retracted than speaker KK, but there is anterior constriction observed for the voiced fricative (see for example /zuˈmi/ for speaker MB).

Analysis of the totals measures showed significant subject variability in the total amount of contact in the palate, with speaker KK having greater amount of contact than speaker MB ($F$ (1,24) =379.84, $p<.0001$). The differences between the two speakers in the total amount of contact for fricatives /s/ and /z/ are displayed in Figures 3 and 4 respectively. Significantly more contact was also found for the /z/ than the /s/ consonant ($F$ (1,24) = 15,780, $p<.0001$). Effects of consonant voicing on total amount of contact for the two speakers are displayed in Figures 5 and 6. Greater amount of contact was also found in the /i/ and less in the /a/ and /u/ environments ($F$ (2,24) = 27,710, $p<.0001$). At the front region of the palate, significantly more contact was again found for speaker KK than speaker MB ($F$ (1,24) =746,072, $p<.0001$). Effect of voicing was also significant, with the voiced consonant /z/ showing more contact than the voiceless /s/ ($F$ (1,24) =24,123, $p<.0001$). Effects of stress and word position were not significant at the 0.05 level.

Results of the COG confirmed significant subject variability in place of articulation between the two speakers ($F$ (1,46) =465,92, $p<.000$). As already observed in the palatograms, speaker’s KK production was consistently found in the anterior region of the palate, while place of articulation for speaker MB was evidently retracted. Speaker variability for fricatives /s/ and /z/ are displayed in Figures 7 and 8 respectively. Significantly more anterior contact was found for /z/ than the /s/ fricative in both speakers ($F$ (1,44) =15,89), $p<.0001$). Word position, stress and vowel context did not induce significant variation.

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Results of the front centrality index showed significant subject variability in the amount of contact in the central region of the palate, with KK showing more contact at the front central region of the palate than MB ($F(1,46) = 8.62, p < .0001$). This suggests the presence of more open articulations for speaker MB. Significantly more central productions were evident in the environment of the /z/ compared to the /s/ sound ($F(1,46) = 5.22, p < .0001$) for both speakers. Effects of vowel context, word position and stress were not statistically significant at the 0.05 significance level. The percentages of the afore mentioned measures are presented in Table 1.

<table>
<thead>
<tr>
<th>Total amount of contact</th>
<th>Alveolar total</th>
<th>COG</th>
<th>Front centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB</td>
<td>KK</td>
<td>MB</td>
</tr>
<tr>
<td>/s/</td>
<td>0.36</td>
<td>0.52</td>
<td>0.16</td>
</tr>
<tr>
<td>/z/</td>
<td>0.41</td>
<td>0.54</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 1. Percentages of total amount of contact, alveolar contact, COG and front centrality for sounds /s/ and /z/ for both speakers.
Figure 1. Percentage frequency of electrode activation over five repetitions for the fricative /s/ in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 2. Percentage frequency of electrode activation over five repetitions for the fricative /z/ in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 3. Speaker variability in total amount of contact for fricative /s/.

Figure 4. Speaker variability in total amount of contact for fricative /z/.

Figure 5. Effect of consonant voicing on the total amount of contact for speaker MB.
Figure 6. Effect of consonant voicing on total amount of contact for speaker KK.

Figure 7. Speaker variability in COG for fricative /s/.

Figure 8. Speaker variability in COG for fricative /z/.
4.1.2. Results for velar place of articulation

Figure 9 displays EPG palatograms for fricative /x/ in the environment /a/ and /u/ for the two speakers. Figure 10 concerns production of the fricative /ɣ/ in the environment of /a/ and /u/. In contrast to the alveolar place of articulation, no important differences are evident on the palatograms between the two speakers for velar fricatives. There seems to be no important difference between /x/ and /ɣ/ or among the different vowel contexts.

Analysis of the total measures showed that there was no significant speaker variation in the amount of contact at the back region of the palate ($F(1,16) = 1.030, p = .325$). Effect of consonant voicing did not trigger significant results ($F(1,16) = 0.29, p = .595$). Similar amount of contact was observed in sounds /x/ and /ɣ/ for both speakers. Results of the COG confirmed that there was no speaker variation in place of articulation between the two speakers ($F(1,28) = 0.003, p = .95$). There was also no significant variation concerning the two consonants ($F(1,28) = 0.740, p = .39$). Analysis of the back central measure showed that there was also no significant subject difference in the number of activated electrodes in the central region of the palate ($F(1,30) = 0.158, p = .694$). Effects of word-position, stress and vowel context were not statistically significant at the 0.05 significant level for any of the afore mentioned measures. Percentages of the measures are presented in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>Total amount of contact (velartotal)</th>
<th>COG</th>
<th>backcentrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB</td>
<td>KK</td>
<td>MB</td>
</tr>
<tr>
<td>/x/</td>
<td>0.17</td>
<td>0.17</td>
<td>0.10</td>
</tr>
<tr>
<td>/ɣ/</td>
<td>0.20</td>
<td>0.16</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Table 2. Percentages of velar total, COG and back centrality in velar fricatives for both speakers.
Figure 9. Percentage frequency of electrode activation over five repetitions for the fricative /x/ in /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 10. Percentage frequency of electrode activation over five repetitions for the fricative /ɣ/ in /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
4.1.3. Results for palatal place of articulation

EPG palatograms for [ç] and [j] are presented in Figures 11 and 12 respectively. Interesting variation in the amount of tongue-palate contact is observed between the two speakers, with speaker KK consistently exhibiting more contact than speaker MB. One important note should be made here. In some cases ([ma'ja], [vrãça]), speaker KK exhibits full contact at the central region of the palate, which is not expected for Greek palatal fricatives. This pattern is probably attributed to the fact that contacts that are placed close together on the palate are sometimes coupled by saliva, causing them to switch on together (Wrench, 2007). It is possible that the full contact observed at some of the patterns of speaker KK is caused by the interconnection of the contacts placed in the center of the palatal zone. It should also be noted that speaker KK did not show any signs of articulation problems while he produced the words with the fricatives [ç] and [j]. Apart from differences in the amount of contact, differences in the place of articulation are evident between the two speakers, with speaker KK showing more anterior contact than speaker MB.

Analysis of the totals measures showed significant subject variation in total amount of contact between the two speakers, with speaker KK having greater contact than speaker MB ($F(1,6) = 99.9, p < .0001$). Greater amount of contact for speaker KK was also found in the back rows of the palate ($F(1,6) = 61.47, p < .0001$). The differences between speaker KK and MB in the total amount of contact for fricatives [ç] and [j] are displayed in Figures 13 and 14 respectively.

Results of the COG showed significant subject variation in place of articulation, with more anterior place of articulation observed in speaker KK ($F(1,26) = 89.92, p < .0001$). There was no variation according to consonant ($F(1,24) = .227, p = .638$). The differences in place of articulation for fricatives [ç] and [j] between the two speakers are displayed in Figures 15 and 16 respectively.

Analysis of the back central measure showed greater amount of contact at the central region of the palate for speaker KK and more lateral contact for speaker MB ($F(1,26) = 996.65, p < .0001$). This suggests more open articulations for speaker MB. However, the fact that some of speaker’s KK EPG patterns showed full contact at the center region of the palate might account for the difference in the amount of contact in the central region of the palate. Effects of consonant, word-position, stress and vowel context were not statistically significant at the 0.05 significant level. The percentages of total amount of
contact, contact at the back region of the palate (velar total), COG and back centrality are displayed in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Total amount of contact</th>
<th>Velar total</th>
<th>COG</th>
<th>backcentrality</th>
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<tr>
<td></td>
<td>MB</td>
<td>KK</td>
<td>MB</td>
<td>KK</td>
</tr>
<tr>
<td>[ç]</td>
<td>0.38</td>
<td>0.55</td>
<td>0.65</td>
<td>0.81</td>
</tr>
<tr>
<td>[j]</td>
<td>0.38</td>
<td>0.52</td>
<td>0.66</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Table 3. Percentages for total amount of contact, velar total, COG and back centrality for speakers MB and KK.
Figure 11. Percentage frequency of electrode activation over five repetitions for the fricative /ç/ in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 12. Percentage frequency of electrode activation over five repetitions for the fricative /ʝ/ in /i/ and /a/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 13. Speaker variability in total amount of contact for fricative [ç].

Figure 14. Speaker variability in total amount of contact for fricative [ʝ].

Figure 15. Speaker variability in place of articulation for fricative [ç].
4.2. Results for /s/ in clusters

4.2.1. Results for /fricative-stop/ clusters

Differences in the production of the fricative /s/ in clusters between speaker KK and MB were also tested in the present study. Figures 17-19 present EPG palatograms for /fricative-stop/ clusters, namely /st/, /sp/ and /sk/ for both speakers. All possible target words in the environment of /i/, /a/ and /u/, in word initial, stressed/unstressed and word medial, stressed/unstressed position were tested. The EPG patterns of the two speakers suggest that there are important differences in the total amount of contact and place of articulation for clusters /st/, /sp/ and /sk/. Similar to the EPG patterns of /s/ as singleton, the patterns of /s/ in clusters show that speaker KK exhibits more amount of contact at the whole region of the palate, while place of articulation is consistently more anterior for all clusters.

Analysis of the totals measures showed significant subject variability in the total amount of contact (F (1,35) = 752.68, p<.0001), with speaker KK exhibiting more contact than speaker MB. For speaker KK, there was significant effect of consonantal context (F (2,27) = 84.741, p<.0001), with total amount of contact decreasing in the order sk > st > sp. Significant variance was also induced due to vowel context (F (2,27) = 18.009, p<.0001), as more contact was evident in the environment of /i/ compared with /a/ and /u/, which did not differ significantly (p =.767). At the front region of the palate, greater amount of contact was evident for /st/ (F (2,27) =55.951, p<.0001), followed by /sk/ and /sp/, which differed significantly with each other (p<.0001). There were no differences according to vowel context (F (2,27) =0.108, p=.898). For speaker MB, amount of contact was also affected by consonantal context (F (2,27) = 7,848, p<.0001), as there was statistically more contact for /sk/ compared with /sp/ (p<.0001). Amount of contact for /st/ did not differ significantly with /sk/ (p=.110) or /sp/ (p=.168). Effect of vowel context was also significant (F (2,27) = 4.117, p<.0001), as significantly more contact was found for /i/, followed by /a/ and /u/. At the front region of the palate, there were no important differences between clusters /st/, /sp/ and /sk/. The difference in the amount of contact at the front region of the palate for speaker KK and MB is displayed in Figures 20 and 21 respectively.
Results of the COG showed that there was also significant variability in place of articulation for the two speakers ($F(1,65) = 1831.54, p<.0001$). For speaker KK, significant variation was induced due to consonantal context ($F(2, 18) = 198.47, p<.0001$), with more anterior contact decreasing in the order st>sp>sk. Effect of vowel context was also statistically significant ($F(2,18) = 10.897, p<.0001$), as more anterior contact was evident in the environment of /i/ compared with /a/ ($p<.0001$) and /u/ ($p<.0001$). Vowels /a/ and /u/ did not differ significantly ($p=.824$). For speaker MB, consonantal context caused significant differences ($F(2,18) = 3748.619, p<.0001$). More anterior contact occurred in /st/ compared with /sk/ ($p<.0001$) and /sp/ ($p<.0001$), while /sk/ and /sp/ did not differ significantly ($p=.217$). Effects of vowel, stress and word position were not significant at the 0.05 level.

Results of the front centrality measure showed that there was significant speaker variation in the amount of contact at the front central region of the palate ($F(1,53) = 9643.66, p<.0001$). For speaker KK, there was significant effect of consonantal context ($F(2,18) = 19.699, p<.0001$), as more contact at the front region of the palate was found for /st/ and /sk/ ($p=.107$) compared with /sp/. Effect of vowel environment was also statistically significant ($F(2,18) = 9.060, p<.0001$), with more contact occurring in the environment of /i/ compared with /a/ and /u/, which did not differ significantly ($p=.784$). For speaker MB, statistically significant effect was induced due to consonantal context ($F(2,18) = 1971.97, p<.0001$), with contact decreasing in the order /st/>/sp/>/sk/. Effect of vowel environment was not significant for speaker MB ($F(2,18) = 1.540, p=.241$). The percentages of total amount of contact, contact at the alveolar region of the palate, COG, and contact at the front central region of the palate are displayed in Table 4.

<table>
<thead>
<tr>
<th></th>
<th>Total amount of contact</th>
<th>Alveolar total</th>
<th>COG</th>
<th>Front centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB</td>
<td>KK</td>
<td>MB</td>
<td>KK</td>
</tr>
<tr>
<td>/st/</td>
<td>0.38</td>
<td>0.60</td>
<td>0.17</td>
<td>0.68</td>
</tr>
<tr>
<td>/sp/</td>
<td>0.36</td>
<td>0.50</td>
<td>0.17</td>
<td>0.53</td>
</tr>
<tr>
<td>/sk/</td>
<td>0.40</td>
<td>0.65</td>
<td>0.15</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Table 4. Percentage of total amount of contact, alveolar total, COG and front centrality measure for clusters /st/, /sp/ and /sk/.
Figure 17. Percentage frequency of electrode activation over five repetitions for the /st/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 18. Percentage frequency of electrode activation over five repetitions for the /sk/-/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 19. Percentage frequency of electrode activation over five repetitions for the /sp-/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
4.2.2. Results for /stop-fricative/ clusters

Figures 22, 23, 24 show EPG patterns for /stop-fricative/ clusters /ts/, /ks/ and /ps/ for speakers MB and KK. Analysis of the total measures showed significant speaker variability in the total amount of contact for /stop-fricative/ clusters ($F(1,50) =477.734, p<.0001$). For speaker KK, significantly more contact was evident in /ts/ ($F(2,16) = 61.030, p<.0001$), followed by /ks/ and /ps/, whose amount of contact also differed significantly ($p<.0001$). Effect of vowel context also induced important differences, as more contact occurred in /i/ ($F(2,16) =11,287, p<.0001$) compared with /a/ and /u/, which did not show important differences ($p=.098$). At the front region of the palate, significantly more contact was found in the decreasing order /ts/>/ps/>/ks/ ($F(2,16) =305.136, p<.0001$). Effect of vowel environment did not induce important differences at the amount of contact at the front region of the palate ($F(2,16) =1,006, p=.388$). For speaker MB, the total amount of contact at the whole palate did not differ according to consonantal context ($F(2,17) =1,207, p=.306$) or vowel environment ($F(2,17) =0,846, p=.447$). However, at the front region of the palate, effect of consonantal context...
was statistically significant \((F(2,17)=3.846, p<.0001)\), as more contact was found for /ts/, followed by /ks/ and /ps/, which did not differ significantly \((p=.460)\).

Results of the COG showed that there were statistically important differences in place of articulation between speaker KK and MB \((F(1,62)=684.671, p<.0001)\). The differences between the two speakers in place of articulation for clusters /ts/, /ps/ and /ks/ are displayed in Figures 22-24. For speaker KK, consonantal context induced significant differences \((F(2,16)=594.559, p<.0001)\), with more anterior contact decreasing in the order /ts/>/ps/>/ks/. For speaker MB, effect of consonantal context was also significant \((F(2,17)=5,097, p<.0001)\), as more anterior place of articulation was found for /ts/, followed by /ps/ and /ks/, which did not differ significantly \((p=.693)\). Effects of vowel environment, stress and word position were not significant at the 0.05 level.

Analysis of the front centrality measure showed significant speaker variation in the total amount of contact at the front region of the palate \((F(1,50)=10,948, p<.0001)\). For speaker KK, the effect of the preceding consonant was significant \((F(2,17)=214,737, p<.0001)\), as more contact was evident in the decreasing order /ts/>/ks/>/ps/. Effect of vowel environment was also significant \((F(2,17)=5,683, p<.0001)\), with more contact for vowels /i/ and /u/ compared with /a/. For speaker MB, there were no differences in the total amount of contact at the front region of the palate according to consonantal context \((F(2,17)=1,207, p=.324)\) or vowel environment \((F(2,17)=0,782, p=.473)\). The percentage of total amount of contact, contact at the alveolar region of the palate, COG, and contact at the front central region of the palate for /stop-fricative/ clusters are displayed in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Total amount of contact</th>
<th>Alveolar total</th>
<th>COG</th>
<th>Front centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB</td>
<td>KK</td>
<td>MB</td>
<td>KK</td>
</tr>
<tr>
<td>/ts/</td>
<td>0.42</td>
<td>0.66</td>
<td>0.29</td>
<td>0.80</td>
</tr>
<tr>
<td>/ps/</td>
<td>0.39</td>
<td>0.53</td>
<td>0.20</td>
<td>0.56</td>
</tr>
<tr>
<td>/ks/</td>
<td>0.42</td>
<td>0.60</td>
<td>0.22</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table 5. Percentage of total amount of contact, alveolar total, COG and front centrality measure for clusters /ts/, /ps/ and /ks/.

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Figure 22. Speaker variability in place of articulation for cluster /ts/.

Figure 23. Speaker variability in place of articulation for cluster /ps/.

Figure 24. Speaker variability in place of articulation for cluster /ks/.
Figure 25. Percentage frequency of electrode activation over five repetitions for the /ts/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 26. Percentage frequency of electrode activation over five repetitions for the /ks/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 27. Percentage frequency of electrode activation over five repetitions for the /ps/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
4.2.3. Results for /fricative-stop-/ clusters

Figures 28, 29 and 30 show EPG palatograms for clusters /str/, /spr/ and /skr/. Analysis of the totals measures showed significant speaker variability in the total amount of contact \( (F (1,32) =740,802, \ p<.0001) \). For speaker KK, significant effect was induced due to consonantal context \( (F (2,9) =12,217, \ p<.0001) \), with more contact for clusters /skr/ and /str/ compared with /spr/. At the front region of the palate, significantly more contact was evident for the cluster /str/ \( (F (2,9) =22,177, \ p<.0001) \) than for clusters /skr/ and /spr/, which did not exhibit important differences \( (p=.135) \). For speaker MB, there was no difference in the total amount of contact among clusters /str/, /skr/ and /spr/ \( (F (2,10) =2,054, \ p=.179) \). The same pattern was also found at the front region of the palate, as the three clusters did not show important differences \( (F (2,10) =0,017, \ p=.983) \).

Results of the COG showed that there were statistically important differences between the two speakers in place of articulation for clusters /str/, /spr/ and /skr/ \( (F (1,38) =452,687, \ p<.0001) \). For speaker KK, there was significant effect of consonantal context \( (F (2,10) =20,089, \ p<.0001) \), with more anterior production in the decreasing order /str/>/spr/>/skr/. The different vowel environments did not induce significant variation in the place of articulation \( (F (2,10) =1,975 \ p=.189) \). For speaker MB, the consonantal context did not affect the place of articulation \( (F (2,10) =0,194, \ p=.827) \). Effect of vowel environment was not significant for speaker MB \( (F (2,10) =3,368, \ p=.076) \).

Analysis of the front centrality measure showed that there was also significant speaker variation in total amount of contact at the front central region of the palate \( (F (1,32) =39,387, \ p<.0001) \), with speaker KK exhibiting more contact than speaker MB. Effect of consonantal context was not significant for speaker KK \( (F (2,10) =2,448, \ p=.136) \) or for speaker MB \( (F (2,10) =0,506, \ p=.618) \). The percentage of total amount of contact, contact at the alveolar region of the palate, COG, and contact at the front central region of the palate for /stop-fricative/ clusters are displayed in Table 6.

<table>
<thead>
<tr>
<th></th>
<th>Total amount of contact</th>
<th>Alveolar total</th>
<th>COG</th>
<th>Front centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB</td>
<td>KK</td>
<td>MB</td>
<td>KK</td>
</tr>
<tr>
<td>/str/</td>
<td>0,36</td>
<td>0,56</td>
<td>0,18</td>
<td>0,64</td>
</tr>
<tr>
<td>/spr/</td>
<td>0,35</td>
<td>0,51</td>
<td>0,18</td>
<td>0,55</td>
</tr>
<tr>
<td>/skr/</td>
<td>0,38</td>
<td>0,58</td>
<td>0,19</td>
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</tbody>
</table>

Table 6. Percentage of total amount of contact, alveolar total, COG and front centrality measure for clusters /str/, /spr/ and /skr/.
Figure 28. Percentage frequency of electrode activation over five repetitions for the /str-/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
Figure 29. Percentage frequency of electrode activation over five repetitions for the /spr-/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).

Figure 30. Percentage frequency of electrode activation over five repetitions for the /skr/ cluster in /i/, /a/ and /u/ contexts, in word-initial and medial position for speaker KK (always displayed on the left) and speaker MB (always displayed on the right).
4.2.4. Results for clusters with different structure

Another important factor that we had to examine in relation to clusters was whether the consonant structure of the clusters led to differences in the EPG frames. Specifically, we examined whether differences existed among clusters /st/, /ts/ and /str/, /sp/, /ps/ and /spr/, as well as /sk/, /ks/ and /skr/.

In relation to clusters /st/, /ts/ and /str/, there were important differences in the total amount of contact for speaker KK \((F(2,17)=92,534, p<.0001)\), with contact decreasing in the order /ts/>/st/>/str/. Effect of vowel contact was also significant \((F(2,17)=7,047, p<.0001)\), with more contact in the environment of /i/ compared with /a/ and /u/, which did not exhibit important differences \((p=.140)\). At the front region of the palate, significantly more contact was evident in the decreasing order /ts/>/st/>/str/ \((F(2,17)=93,939, p<.0001)\). Vowel environment also induced significant differences, with more contact for vowels /u/ and /a/ compared with /i/ \((F(2,17)=17,628, p<.0001)\). For speaker MB, the total amount of contact was also affected by the consonant structure \((F(2,160)=9,159, p<.0001)\), as more contact was found for /ts/ followed by /st/ and /str/, which did not differ significantly \((p=.203)\). Effect of vowel environment was not statistically significant \((F(2,16)=1,866, p=.100)\). At the front region of the palate, significantly more contact was again found for /ts/ \((F(2,16)=13,081, p<.0001)\) compared with /st/ and /str/, which did not have important differences \((p=.592)\). Effect of vowel environment was also significant \((F(2,16)=4,423, p<.0001)\), with more contact for vowels /u/ and /a/ compared with /i/.

Results of the COG showed that cluster structure induced significant differences in place of articulation for speaker KK \((F(2,17)=6,313, p<.0001)\). Specifically, more anterior contact was evident for /ts/ compared with /st/ \((p<.0001)\) and /str/ \((p<.0001)\), while the last two did not show important differences \((p=.439)\). Effect of vowel context was also significant, with more anterior production for vowels /a/ and /u/ compared with /i/ \((F(2,17)=18,944, p<.0001)\). For speaker MB, significantly more anterior contact was found for /ts/ \((F(2,16)=11,557, p<.0001)\), followed by /st/ and /str/, which did not differ significantly \((p=.236)\). There was also significant effect of vowel environment, with more anterior contact in vowel /a/ and /u/ and less in vowel /i/ \((F(2,16)=5,530, p<.0001)\).

Results of the front centrality measure showed significant effect of cluster structure in the amount of contact at the front region of the palate for speaker KK \((F(2,17)=100,55, p<.0001)\). Specifically, more contact was evident for /ts/, followed by /st/ and /str/ and cluster /st/ showing more contact than /str/ \((p<.0001)\). For speaker MB, significantly more contact occurred in /ts/ \((F(2,16)=4,204, p<.0001)\), followed by /st/ and /str/, which did not differ significantly \((p=.377)\). Effect of vowel context was not statically significant at the 0.05 level for neither of the speakers.
Figure 31. Differences in total amount of contact in clusters /st/, /ts/ and /str/ for speaker KK.

Figure 32. Differences in total amount of contact in clusters /st/, /ts/ and /str/ for speaker MB.

Figure 33. Differences in place of articulation in clusters /st/, /ts/ and /str/ for speaker KK.
In relation to clusters /sp/, /ps/ and /spr/, the analysis of the total measures for speaker KK showed that there was significantly more contact for cluster /ps/ ($F(2,15)=8.984$, $p<.0001$), followed by /spr/ and /sp/, which did not differ significantly ($p=.597$). At the front region of the palate, there was no difference in the amount of contact among these clusters ($F(2,15)=2.573$, $p=.109$). For speaker MB, significantly more contact was evident for /ps/ ($F(2,15)=5.825$, $p<.0001$), while /sp/ and /spr/ did not exhibit important differences ($p=.478$). At the front region of the palate, there were no important differences among clusters ($F(2,15)=1.528$, $p=.249$).

Results of the COG showed that the structure of the clusters did not induce significant variation in place of articulation for speaker KK ($F(2,15)=0.503$, $p=.614$). However, for speaker MB place of articulation varied among the clusters /sp/, /ps/ and /spr/ ($F(2,15)=2928.68$, $p<.0001$), with more anterior contact for cluster /sp/, followed by /ps/ and /spr/, which did not differ significantly ($p=.879$). In relation to contact at the front region of the palate, differences among clusters again concerned only speaker MB, with more contact for clusters /ps/ and /spr/ ($F(2,15)=3462.06$, $p<.0001$) and the least contact for cluster /sp/.

Finally, we examined the differences for the two speakers in the clusters /sk/, /ks/ and /skr/. For speaker KK, the total amount of contact differed among the clusters ($F(2,13)=9.507$, $p<.0001$), with significantly more contact for cluster /sk/, followed by /ks/ and /skr/, which did not exhibit important differences ($p=.329$). Effect of vowel environment was also significant ($F(2,13)=11.527$, $p<.0001$), as more contact was found for vowel /i/ compared with /a/ and /u/. At the front region of the palate, more contact occurred in the descending order sk>skr>ks ($F(2,13)=27.377$, $p<.0001$). For speaker MB, the total amount of contact did not differ according in the different clusters ($F(2,13)=2.512$, $p=.120$), but there was effect of vowel environment ($F(2,13)=6.588$, $p<.0001$), with more contact in vowel /i/, followed by /a/ and /u/, which did not differ significantly ($p=.403$). At the front region of the palate, more contact was found for cluster /ks/ ($F(2,13)=8.125$, $p<.0001$) compared with /sk/ and /skr/. Effect of vowel context was not significant at the 0.05 level.
Results of the COG showed that for speaker KK, a more anterior place of articulation was found for cluster /sk/ than for /skr/ and /ks/ ($F (2,13) = 38,569, p < .0001$). The same pattern was observed for speaker MB, as more contact was evident for cluster /sk/ ($F (2,13) = 2001.873, p < .0001$) compared with /ks/ and /skr/, which did not exhibit significant differences ($p = .665$). Regarding differences at the front central region of the palate, speaker KK showed more contact for clusters /sk/ and /ks/ and less for /skr/ ($F (2,13) = 5,191, p < .0001$). More contact was also found in the environment of /i/ ($F (2,13) = 10,070, p < .0001$) compared with /a/ and /u/. For speaker MB, significantly more contact at the central region of the palate was found was clusters /ks/ and /skr/ compared with /sk/ ($F (2,13) = 449,360, p < .0001$). As it is also evident on the EPG patterns (Figure 18), speaker MB shows a very open place of articulation for cluster /sk/.
4.3. DDK rates

Table 3 presents the mean number of syllables each participant produced per second. Variability in the performance of the two subjects was observed in the DDK task, as there was a significant difference in the number of repetitions produced by speaker KK ($M=2,986$, $SD=1,018$) and the number of repetitions produced by speaker MB ($M=1,894$, $SD=0,408$); $t(8) =2.20$, $p<.0001$). As one can see in following Table, both participants had higher DDK rates in the single syllable task (pa, ta, ka) and lower in the syllable sequence task (ta_ka, pa_ta_ka). The number of data derived from the two speakers does not allow for a statistical analysis of the data to examine whether single syllables or sequences of syllables proved more demanding for each speaker.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>/pa/</th>
<th>/ta/</th>
<th>/ka/</th>
<th>/ta_ka/</th>
<th>/pa_ta_ka/</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>2,07</td>
<td>2,06</td>
<td>2,37</td>
<td>1,64</td>
<td>1,33</td>
</tr>
<tr>
<td>KK</td>
<td>3,75</td>
<td>3,68</td>
<td>3,75</td>
<td>2</td>
<td>1,75</td>
</tr>
</tbody>
</table>

Table 7. Mean rate in syllable per second.
5. Discussion

The present study examined electropalatographic data during the production of fricatives by a Greek adult with Down Syndrome. Normative data was obtained from an age-matched Greek speaker. The word list consisted of 149 real words containing the fricatives of the Greek language, namely /s/, /z/, /l/, /x/, /ɣ/, [ç] and [ʝ]. Electropalatographic analysis concerned the total amount of contact, the center of gravity and the centrality index in the production of consonants. The effect of lexical stress, word position and vowel context (/i/, /a/ and /u/), as well as the interaction among these factors, were tested. Apart from singletons, clusters containing the alveolar fricative /s/ were examined in the same contexts, namely /st/, /ts/, /sk/, /ks/, /sp/, /ps/, /str/, /spr/ and /skr/. With regard to the Greek language, there is not to our knowledge any previous study examining the articulation of fricative consonants using EPG. Our results are discussed in relation to the respective bibliography for other languages.

Apart from EPG data, the two speakers were also tested in a DDK task. DDK provides valuable information about speech motor control and it is a technique usually employed in pathological speech. The speakers were asked to repeat syllables or a sequence of syllables as many times as possible within a certain time frame. The syllables examined in the present thesis were /pa/, /ta/, /ka/ and the sequences /ta_ka/ and /pa_ta_ka/. Their choice is based on the fact that they test the subject’s ability to make rapid articulatory movements to produce the target syllables, as well as to rapidly exchange articulatory placement for the repetition of the sequences. Results obtained from the EPG and the DDK are discussed in relation to the existing theories about speech impairment and are expected to shed some light on the complex nature of speech production in DS.

5.2. EPG results

The main aim of the present thesis was to examine the EPG patterns of a Greek adult speaker with DS and compare them with normative data from an adult speaker. As already mentioned, there is no previous EPG study examining the articulatory patterns of people with DS in the Greek language. Previous research is limited to the English language, where important differences were observed between speakers with DS and the control group (Hamilton, 1993, Timmins et al., 2007). The comparison between the findings of our study and previous experiments is treated with caution due to the language constraints. Apart from that, it should be noted that the Greek speaker with DS exhibited a number of speech disfluencies while performing the task. The results of our study are thus discussed taking into consideration the effects that such disfluencies could have had on his EPG patterns.
Significant difference in the total amount of contact and place of articulation for Greek alveolar fricatives were observed between the two speakers. Amount of contact at the whole palate, as well as amount of contact at the front rows of the palate (corresponding to the alveolar zone) was consistently higher for speaker KK than speaker MB. One of the most striking findings concerned the differences in place of articulation. For speaker MB, there was consistently no constriction for alveolar fricative sounds in the front rows of the palate, suggesting a retracted place of articulation for speaker MB, with a greater degree of retraction concerning the /s/ than the /z/ sound. More open articulations were also evident in speaker MB, with more contact in the lateral sides of the palate. Speaker MB exhibited incomplete contact (undershoot) for alveolar place of articulation. Our findings are not in agreement with Hamilton (1993) who reported increased palate contact resulting in complete closure for fricatives /s/ and /ʃ/. However, two important observations should be made in relation to Hamilton’s participants, though. First of all, Hamilton’s examination concerned the English language and differences between her and our results could be attributed to language constraints. Secondly, Hamilton reported that, during the production of some alveolar sounds, the tongue tip protruded out form the incisor teeth and, as a result, was not used for articulation. Given that that tongue blade was probably used for articulation, Hamilton explained that the increased palate contact observed during the production of the alveolar fricatives could also be attributed to the fact that a wider part of the tongue was used for the production of the target sounds. The speakers’ inability to control the tongue tip probably indicated difficulty in controlling the tongue tip itself, which probably results from hypotonia. This might account for the different results between Hamilton’s and our study.

Variability between the two speakers was also observed in palatal fricatives [ç] and [ʝ]. Differences were shown both in the amount of contact at the back region of the palate and place of articulation. Speaker KK showed greater amount of contact and more anterior productions than speaker MB, whose palate contact was characterized by a grooved pattern. However, it should be noted that some of the EPG patterns of speaker KK were characterized by full contact at the central region of the palate. As Wrench (2007) explained, this is a pattern which has usually been observed in studies making use of the Articulate Instrument palate, as contacts that are placed too close together are sometimes connected by saliva and, therefore, switched on and off together. It is possible then that the differences between the two speakers in contact at the central region of the palate is attributed to the fact that some contacts in speaker’s KK palate were interconnected and showed full contact. In relation to velar fricatives /x/, /ɣ/, there were no important differences between the two speakers. Both speaker exhibited similar
patterns of contact and placement for the two consonants. To our knowledge, there is no previous study examining contact for palatal and velar fricatives in adults with DS.

Apart from singletons, we were interested in investigating the production of fricative /s/ in clusters. The accurate production of clusters is considered a significant milestone in a subject’s phonological development, as it reflects a maturation of the speech motor mechanism and anatomical development (Ingram, 1991). The examination of the production of fricative /s/ in clusters also yielded interesting results. Speaker KK consistently exhibited more contact than speaker MB for fricative /s/ in clusters, as well as a more anterior place of articulation and more contact at the central region of the palate. Specifically, in relation to /fricative-stop/ clusters (/st/, /sp/ and /sk/), a greater amount of linguopalatal contact was evident in the EPG frames of speaker KK than in those of speaker MB. For both speakers, greater amount of contact was found for cluster /sk/, while significantly more anterior place of articulation concerned cluster /st/. Speaker KK also exhibited more contact at the front region of the palate for cluster /st/, while speaker MB did not show differences in place of articulation among clusters /st/, /sp/ and /sk/. Speaker MB consistently exhibits more posterior contact, as well as contact at the lateral side of the palate, which indicates more open articulations.

Significant differences between the two speakers also concerned /stop-fricative/ clusters (/ts/, /ps/ and /ks/). Once again, amount of contact was greater for speaker KK than speaker MB. For both speakers, the greatest amount of contact, both at the whole and the front region of the palate, concerned the cluster /ts/. Speaker KK showed more contact for /ks/ than /sp/ and more contact was evident in the environment of vowel /i/. However, speaker MB did not exhibit differences according to vowel environment and showed the same amount of contact for clusters /ks/ and /ps/. Apart from that, place of articulation did not differ for /ks/ and /ps/ in speaker MB as in speaker KK. Speaker KK also showed more contact at the front central region of the palate for all clusters in the descending order /ts/>/ks/>/ps/, while speaker MB again showed more lateral contact for the clusters, which did not differ in the amount of contact at the central region of the palate.

The items falling into the /fricative-stop-r/ category, namely /str/, /spr/ and /skr/, proved the most challenging for speaker MB to produce. During the recordings, it was difficult for speaker MB to discriminate among clusters /str/, /spr/ and /skr/ when producing the experiment items. The results of the analysis showed that speaker MB did not exhibit differences in the total amount of contact or place of articulation among these clusters. The contact that he exhibited was consistently reduced in comparison with speaker KK and more posterior. Speaker KK exhibited more contact for clusters /str/ and /skr/ at the whole palate and more contact for cluster /str/ at the front region of the palate.
The final question addressed in relation to clusters was whether different structure would induce differences for the two speakers; namely, whether differences would be observed among clusters /st/, /ts/ and /str/, /ks/ and /skr/, /sp/, /ps/ and /spr/. In relation to the first category, both speakers exhibited more contact for cluster /ts/. Speaker KK again exhibited more contact than speaker MB. More contact was also evident in /st/ than /str/ for speaker KK, while speaker MB showed the same amount of contact for the two clusters. What was interesting about the second category, namely clusters /sp/, /ps/ and /spr/, was that speaker MB exhibited more anterior contact for cluster /sp/ than /ps/ and /spr/, while no differences in place of articulation were found for speaker KK. In relation to /sk/, /ks/ and /skr/, more contact was evident for /sk/ in both speakers.

Given the results of the present thesis, the question that needs to be addressed is what might have left to the significantly decreased and incomplete palate contact than was evident in the vast majority of the palatograms of speaker MB. Undershoot is a feature that was found in dysarthric children by Hardcastle et al. (1985). In their study, speakers with dysarthria presented with incomplete anterior closure for alveolar stops and incomplete anterior contact in the lateral side of the palate for alveolar fricatives. In our results, incomplete contact concerned the central, not the lateral side of the palate, but it is possible that hypotonia of the tongue was responsible for the contact observed in our participant. In order to discuss this question of what led to fricative undershoot thoroughly, some important characteristics about the speech of our participant should be taken into account. Speaker MB presented with a number of speech disfluencies when performing the task. Speech disfluencies are a common characteristic of the speech of people with DS, with a high percentage of these individuals being characterized as 'stutterers’ or ‘clutterers’ (Willcox, 1988, Preus, 1996, Ward, 2018). Our participant had not received a diagnosis of stuttering, but it was observed that blockages and sound prolongations usually impeded normal flow of speech. Such speech disfluencies also persisted in his spontaneous speech. The task for the present thesis had to be modified several times to ensure that the speech of speaker MB was as fluent as possible. However, a comparison of our results to the ones concerning the investigation of stutterers’ EPG palate contact was deemed necessary.

Incomplete contact for fricative sounds was a feature found in Forster and Hardcastle’s (1988) EPG study of two adults who stuttered. Similar to our study, the participants were asked to repeat certain words in order to examine production of alveolar stops and fricatives and velar stops using EPG. The same results were also found in Wood (1995). Retracted place of articulation and a grooved pattern were evident for /s/ targets, while for the voiced fricative, contact was spatially more similar to the normal speaker. The findings from these two studies...
agree with our findings on the incomplete contact in alveolar fricatives. It is then possible that speaker’s MB articulation of the certain sounds was influenced due to the speech disfluencies he exhibited.

According to Forster and Hardcastle (1988), fricative undershoot should be seen as a sign of a subject’s inability to appropriately control muscular activity of the tongue for the production of the target sound. Incomplete contact might result from the complex articulatory control which fricative production requires. The same opinion was also expressed by Wood (1995), who supported that the weak articulation of fricatives also found in her study was the result of poor motor control at an articulatory level. Our results, then, lend some support to the theory that speech impairment in DS might be the result of a breakdown in the system that controls the production of speech and, therefore, could be viewed as a motor control disorder.

The fact that EPG contacts of speaker MB were similar to those found in Forster and Hardcastle (1990) and Wood (1995) raise another important question about the speech mechanism of people with DS who stutter and those who have fluent speech. Devenny et al. (1990) gave evidence that the motor organization of DS of stutter is different than that of fluent speakers. In her study, she compared the performance of the two groups in motor tasks of varying complexity and found that stutterers with DS were faster than fluent speakers on simple, repetitive tasks (such as the DDK task), but slower on tasks that required more complex movements. If people with DS exhibit differences according to the level of disfluency their speech exhibits, then it might be possible that our results about fricative undershoot contradicted to Hamilton’s (1993) results of fricative overshoot due to the many disfluency incidents that occurred in speaker’s MB speech. Once more it is important to note that speaker MB was not classified as a stutterer by his speech pathologist and the calculation of PCC indicated a mildly moderate degree of speech impairment (prolongations and blockages included).

5.3. DDK rates

In the DDK task, speaker MB presented lower rates than speaker KK. Slower DDK rates have been associated with dyspraxic speech, as they indicate the subject’s difficulty in altering between articulatory movements for the production of sounds (Hamilton, 1993). However, what we need to note for our participant is the noticeable number of speech disfluencies observed in his speech, that might have affected his performance in the DKK task as well.
In previous studies addressing DDK in DS, different methodologies were employed. Hamilton (1993) examined how many seconds each participant needed for the production of a certain number of syllables, while McCann and Wrench (2007) based their results on number of syllables per second. The methodology used in the latter study was also employed in the present thesis. Measurement of DDK rates indicated that speaker MB produced significantly slower rates than speaker KK. This finding is not in agreement with MacCann and Wrench (2007) who reported that differences between the children with DS and the typically-developing concerned only accuracy and not rate. One thing should be noted here though. The comparison between our study and MacCann and Wrench has a very important difference, the age of the participants. Increased oral DDK rate is correlated with increased age, a phenomenon which was often attributed to biological factors or cognitive gains that we acquire in the course of our life and development (Ziegler, 2002, Nip & Green, 2013). Hamilton (1993), on the other hand, tested adults with DS, but employed a different methodology, as she measured the seconds each participant needed to produce a certain number of syllables. The results of her study indicated differences between the DS and the comparison group, as the former produced significantly lower DDK rates than the latter. Our results, then, agree with Hamilton in the decrease in DDK rates by people with DS. Regarding the different methodologies, we should mention that up to date, there is disagreement regarding the task-specificity in oral DDK, as well as the theoretical impact of each different type on the understanding of motor speech disorders. The slower DDK rates support the theory that speech impairment in DS might be attributed to poor speech motor control. The difficulty in rapidly repeating CV syllables and sequences is a sign of motor sequencing problems, which is often manifested in speakers with dyspraxia (Henry, 1990).

6. Conclusion

Research on speech production of people with DS has proposed various theories concerning possible impairments in the processes that are required for successful speech production. In the present study, the adult with DS showed signs of both dysarthric and dyspraxic speech, suggesting that speech impairment in DS results from difficulties at different levels of the speech production process.

Incomplete contact found in the majority of the fricative singletons and clusters points to an articulatory impairment which could result from hypotonia. Hypotonia of the tongue, which has been connected to DS, is typically a feature of dysarthric speech and implies problems in carrying out the appropriate tongue movements for the target sounds. Due to the
fact that our participant exhibited a number of speech disfluencies, a feature connected with dyspraxic speech, a comparison between our findings and those of people with speech disfluencies was carried out. Undershoot in fricatives, which results in incomplete contact, was also found in participants of Forster and Hardcastle (1990) and Wood (1995) who stutter. Since stuttering and, generally, speech disfluencies, is considered a state which results from a breakdown in motor programming, we might suggest that the similarity in the articulatory patterns found in these studies and ours lends some support to the theory assuming that speech impairment in DS is related to apraxia of speech. The specific conclusion is reached based also on the results from the DDK task, which revealed slower DDK rates for speaker MB than speaker KK. Such sequencing problems usually manifest in speakers with apraxia and are a sign of motor programing deficits.

Limitations and further research

In the present thesis we tried to contribute to the investigation of speech impairment in the DS population. We should mention, though, that our sample was small and data should be elicited from more speakers, in order to reach firmer conclusions about the articulation of Greek speakers with DS. When we study pathological speech and people with developmental or acquired disorders, it is also important to take into consideration that individuals exhibit variability. Speaker DS, for example, presented with a high incidence of speech disfluencies, which are characteristic of many people with the specific syndrome. It would, therefore, be important for future research to delve more into the nature of speech disfluency in DS and examine how it might affect their articulation and overall speech intelligibility. Data should also be derived from spontaneous speech, which often provides us with more insightful information about the speech of an individual. An important remark should also be made in relation to the technique employed in this study. EPG patterns provide us with visual information about tongue-palate contact, but do not clarify which part of the tongue makes the contact (see above Hamilton, 1993). It is important, then, to ensure that the production of the speaker we test is not affected by the involvement of another articulator. For example, when examining people with DS, we should inquire whether our subject has undergone glossectomy and whether the tongue seems to protrude and, as a consequence, affect our results. Apart from EPG, which represents an objective measurement tool, ultrasound can also be used to examine how different sounds are distorted in spontaneous speech samples. This might also facilitate the
study of coarticulation, which is considered to give important information about the etiology of speech impairment in groups of people with a range of speech problems.
References


Φωνολογικό Τεστ Πανελληνίου Συλλόγου Λογοθεραπευτών (1995)
The target words used in the present thesis were presented with a Power Point presentation, where the speakers were presented pictures while listening the words they had to repeat.

For the Greek fricative singletons, the following corpus was compiled:

/saka/ /sima/ /supa/ /pa'sa/ /ni'si/ /su'su/
/hsa'ki/ /si'ra/ /su'ja/ /pasa/ /li'si/ /0asu/

/zari/ /zimi/ /zugla/ /xa'za/ /pe'zi/ /zu'zuni/
/za'rija/ /zi'mja/ /zu'mi/ /γaza/ /rizi/ /kuzu'lo/

/χa'di/ /χufita/ /fita/ /a'γuri/
/χa'ra/ /χu'rama/ /taxa/ /paχu'lo/

/γala/ /γuri/ /ta'γari/ /si'γi/ /pa'γuri/
/γa'ti/ /γu'di/ /'raγa/ /'ziγi/ /'maγulo/

/çi'na/ /çi'umor/ /o'ça/ /pa'çi/
/çi'mi/ /vraça/ /'nici/

/ja'xa/ /jiri/ /ma'ja
/ji'ni/ /'maja/

For the Greek clusters, the following corpus was compiled:
/skrapa/ /skrinio/ /skrutz/ /pro'skru/ /proskrusi/