European Journal of Special Education Research
ISSN: 2501 - 2428
ISSN-L: 2501 - 2428
Available on-line at: www.oapub.org/edu

doi: 10.5281/zenodo.3339250
Volume 4 | Issue 4 | 2019

DIFFERENCES BETWEEN DYSLEXIC STUDENTS AND CONTROLS MATCHED FOR EDUCATIONAL LEVEL IN WORD INTELLIGIBILITY AND TEXT COMPREHENSION PRESENTED VIA SYNTHETIC AND NATURAL SPEECH

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Abstract:
This study investigated intelligibility and text comprehension for natural and synthetic speech held by a group of dyslexic students and their controls matched for educational level-school grade. Results have shown that both groups identified words and sentences better in natural speech. Dyslexic students however had shown worst performance in synthetic speech than controls. Overall, a significant difference has been observed between the two groups concerning their text comprehension in natural versus synthetic speech.

Keywords: intelligibility; comprehensibility; synthetic speech; dyslexia; text-to-speech, controls, educational level

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1. Introduction

It is more than well documented that students with Specific Learning Disabilities –like Dyslexia- struggle with reading and spelling difficulties (Boada & Pennington, 2006). These major difficulties in their reading process, cannot be attributed to poor hearing or vision, low intelligence, general neurological problems or inadequate educational opportunities (Pavlidis, 1981a,b; Snowling, Hulme and Goulandris, 1994; Snowling, Nation, Moxham, Gallagher and Frith, 1997). Had the evidence in the literature been surmounting and unequivocal that individuals with dyslexia are impaired in the processing of phonological information that is crucial to learn to read and write in alphabetic script (Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008; Sprenger-Charolles, Colé, & Serniclaes, 2006) led researchers to an overt consensus that no matter the bidirectional relation between reading and sensitivity to phonological structure, children with dyslexia have difficulty constructing, maintaining, and retrieving explicitly phonetic representations. However regarding what Olson (1992) had earlier on suggested that the phonological processing might also entail the segmentation of words into their constituent sounds for speaking and listening, urged many researchers (Ziegler, Pech-Georgel George, & Lorenzi, 2009) to claim that deficits in speech processing might also be involved in an impaired reading process and acquisition.

Several studies on the perceptual discrimination of speech sounds have reported categorical perception deficits in dyslexics (De Weirdt, 1988; Godfrey, Syrdal-Lasky, Millay, & Knox, 1981; Reed, 1989; Serniclaes, Sprenger-Charolles, Carré, & Demonet, 2001). Dyslexics had shown deficits not only when they had to discriminate variants of the same phoneme alone but also when they had to label these variants alone, and when they had to discriminate versus label the variants of the same phoneme. Two studies carried out by Godfrey *et al*. (1981) and by Werker and Tees (1987) comparing the observed discrimination scores with those expected from the labeling data, found that the discrepancy was larger for the dyslexic children than that of controls, something that was interpreted as a kind of categorical perception deficit on their behalf. Other studies (Serniclaes, Sprenger-CharollesCarre, & Demonet, 2001) suggested that dyslexics were less efficient in categorical perception than average readers especially in the way in which they perceive phonetic contrasts. That happened as their discrimination peak was reduced as opposed to the one by the average readers. Finally, a study by Blomert, Mitterer, and Paffen (2004) comparing the slopes of the labeling curves, found for once again that dyslexics had defined the category boundaries less sharply than the average readers. However, when researchers used both chronological and reading level controls (Serniclaes, Van Heghe, Mousty, Carre & Sprenger-Charolles, 2004), failed to find significant differences between dyslexics and their reading level controls.

It is noteworthy that the former studies investigating speech perception in dyslexics relied on synthetic speech (Hurford & Sanders, 1990) which is an experimental paradigm, under complete control, since the experimenter can freely vary one parameter each time and assess the sensitivity of the listener to this particular parameter (Zade, Ardil & Sharifova, 2013). Nevertheless, the advantages that the former experimental use provides, is still in question by the scientific community whether results obtained by synthetic speech could be generalized to speech perception.

Thus studies by (Godfrey, Syrdal-Lasky, Millay, and Knox, 1981), comparing performances on two synthetic continua, (/ba/–/da/ and /da/–/ga/) (*consonant-vowel discrimination /ba/-/da/, /da/-/ga/*), found that dyslexics were significantly less consistent than their controls in the identification process of these continua, even at their extremes points (*showing shallower identification functions)*. Other studies have reported similar results for synthetic continua /ba/–/da/ (Reed, 1989; Werker & Tees, 1987), for /pö/–/tö/ (De Weirdt, 1988), and for /sa/–/sta/ (Steffens, Eilers, Gross-Glen, & Jallad, 1992). Such an inconsistent identification on behalf of dyslexics -on synthetic continua suggest that their difficulties in the former experimental paradigms might have been primarily in identifying phonetically similar, though phonologically contrastive, synthetic syllables and that the speech categories might have been, for unknown reasons, broader and less sharply in children with reading disability (dyslexia) than in controls.

More recently Blomert and Mitterer's (2004) compared the performance of dyslexic and control participants for natural and synthetic speech by generating two continua (/ta/ to /ka/ and /ba/ to/da/) based on natural speech and synthetic speech. They observed that the deficit was not observed in the slopes of the identification curves but in the less consistent responses of the dyslexics at the endpoints of the synthetic continuum. No significant differences were found between the two groups when the stimulus continuum based on natural speech. So no speech-perception deficit in dyslexia was found with these stimuli. Researchers' suggested that a categorical-perception deficit, if there was any, could be found only in the synthetic speech continuum. Hence, dyslexics might have been simply less able to adapt to the range of novel stimuli they hear in a categorical-perception task with synthetic stimuli rather than be poor in perceiving speech stimuli. In contrast the control group was better able to apply their phonological categories, built on natural speech consistently to the novel synthetic stimuli compared to their dyslexic counterparts. Given the former results Blomert and Mitterer's (2004) argued that dyslexics might not have after all any deficit in the perception of short, acoustic transients (Serniclaes, Sprenger-Charolles, Carré, & Demonet, 2001). And that's because if such a deficit was present, it should have been observed with synthetic as well as natural speech continua based on manipulating formant transitions.

Importantly a study by Rosen Manganari (2001) was in an agreement with Blomert and Mitterer's (2004) results. Researchers could not report or observe a deficit present with synthetic as well as with natural speech continuum in dyslexics. If these findings be combined with the above studies results about intelligibility of synthetic speech systems by people without disabilities *-who have consistently shown significantly higher levels of intelligibility for natural speech than for synthetic systems-* (Duffy & Pisoni, 1992; Koul & Allen, 1993) would make not only implausible the assumption that dyslexics might have a deficit in the perception of short acoustic transients, but it could easily suggest an account where a deficit is located more in the phonetic transformation of auditory stimuli to lexical/phonological representations (Studdert-Kennedy, 2002; Tunmer, Greany, 2009). Future research should be needed perhaps in different orthographic scripts for elucidating further this account.

Today the ultimate purpose of text to speech systems (TTS) is to transform a text-based message of unlimited or unrestricted vocabulary into spoken form without the necessity of pre-recording (Fellbaum & Kouroupetroglou, 2008; Zade, Adril & Sharifiva, 2013). According to Koul (2003), "synthetic speech perception" is usually discussed in the literature with regard to intelligibility and comprehension. He stated that intelligibility is the listener's ability to recognize/identify phonemes and words when they are presented in isolation while comprehension involves the performing of a higher level processing, the extraction of the underlying meaning from the acoustic signals of speech.

Thus several studies regarding the intelligibility and comprehension of synthetic speech systems by people without disabilities have consistently shown significantly higher levels of intelligibility and comprehension for natural speech than for TTS – synthetic systems (Duffy & Pisoni, 1992; Koul & Allen, 1993; Reynolds & Fucci, 1998; Reynolds & Jefferson, 1999). Given that online measures, such as response latencies, were used in these studies in order to be assessed the cognitive load placed on individuals by synthetic speech, researchers had systematically reported significant differences in the abilities of listeners to identify/ comprehend various stimuli in synthetic speech compared to natural one.

As far as the comprehension of sentences and narratives are concerned, Koul (2003) stated that their accuracy levels are dependent not only on the quality of the speech synthesizer but also on factors such as the complexity of the task, the presence or absence of predictable context, the rate of presentation, the speech-output method and the presence or not of a background noise. Consequently synthesized speech quality is difficult to be assessed, and thus many different scales and test procedures have been proposed in the literature (Grancharov & Kleijn, 2008). Today, the commercially available speech synthesis systems are based either on rule-based speech synthesis (formant synthesizers) or on re-synthesis by concatenation of recorded speech units (typically diphones) Schroeter, (2008). The last decade the corpus-based speech synthesis has become popular in speech synthesis because produces the most natural quality (Dutoit, 2008).

However the level of difficulty that characterizes the assessment of synthesized speech quality, the basic quality measures that a speech synthesis system should possess, are speech intelligibility, naturalness, and speech expressivity (Grancharov & Kleijn, 2008). Expressivity refers to parameters of voice modulation that allow humans to express and identify emotions, intentions, and attitudes (Campbell, 2008). Quite recently, Kouroupetroglou, (2015) included the term "document accessibility" in the quality measures that the synthesized speech should provide to the print disabled readers (blind, or learning disabled-dyslexic readers). "Accessibility" as a term maintains compatibility between content of a document and the technology agent of the reader. Today the most commonly used text-to-speech systems do not take into account the semantics and the cognitive aspects of the presentation elements or text signals (Kouroupetroglou, 2015). Nevertheless the most natural voice quality is provided by concatenative systems, such as DEMOSTHeˈNES (used in the present study), compared to the more robotic rule-based formant synthesizers such as DECtalk1. In a series of psychoacoustic experiments using similar acoustic patterns to the present study, the results for DEMOSTHeˈNES ranged from 94.5% to 96.47% correct responses for participants with and without visual impairments, respectively, in single word tasks; and from 97.5% to 98.1% correct responses respectively, in single sentence tasks (Argyropoulos, Papadopoulos, Kouroupetroglou, Xydas, & Katsoulis, 2007). Given that these results were comparable to results for the DECtalk (one of the most widely used TTS speech synthesizer in the augmentative and alternative communication (AAC) applications) as Koul and Hester, (2006) suggested, reassured us that DEMOSTHeˈNES was the appropriate speech synthesizer for examining the perception of our dyslexic group with respect to intelligibility and comprehension in synthetic and natural speech.

Notwithstanding despite the growing amount of data on the 'synthetic speech perception' by people with no disabilities, there has been limited research on the intelligibility and comprehension of synthetic speech systems by dyslexics and people with visual impairments (Hensil & Whittaker, 2000). Even far more important is that research on the intelligibility and comprehension of synthetic speech systems by Greek dyslexic people has been seriously overlooked. There is no any documented research that had ever addressed dyslexics' sensitivity either to a synthetic continuum or either to a synthetic presentation of words/or sentences. Now days in Greece Text To Speech (TTS) systems are used especially by individuals with visual impairments in order to meet their daily, professional, and educational needs (Freitas & Kouroupetroglou, 2008; Goudiras, Papadopoulos, Koutsoklenis, Papageorgiou, & Stergiou, 2009; Papadopoulos & Koutsoklenis, 2009). In a recent study involving individuals with visual impairments, Papadopoulos, Koutsoklenis, Katemidou, and Okalidou (2009) found that their participants demonstrated significantly better performance when identifying words and sentences presented via natural speech than via synthetic speech. Furthermore when Papadopoulos, Argyropoulos, and Kouroupetroglou (2008) examined intelligibility and comprehension of students with and without visual impairments who were asked to repeat acoustic patterns produced by synthetic speech, their participants with visual impairments responded correctly significantly more frequently than their sighted peers.

Therefore, regarding the above studies and in combination with the compiling evidence about TTS systems in people without learning disabilities, it was thought that it would be interesting to examine the levels of intelligibility of synthetic speech by Greek individuals with and without dyslexia, and investigate further whether there are any differences in their intelligibility and comprehension of various stimuli presented in synthetic versus natural speech. Could it be the case where the Greek dyslexics respond more correctly when are asked to identify acoustic patterns being produced by natural speech than by synthetic speech or the vice versa. Could their levels of intelligibility in both speech conditions suggest anything about the way by which Greek dyslexics identify words or sentences in natural versus synthetic speech? Could lastly but not least both their levels of intelligibility and comprehension of synthetic speech suggest and consequently lead to a development of appropriate educational aids that could possibly enable dyslexics to overcome reading deficits.

The ultimate goal of the present study was to compare the level of speech perception of the two groups with respect: a) to the intelligibility of words/and sentences and b) to the comprehension of the texts produced both in synthetic and natural speech.

The aims were as follows:

a) To compare the intelligibility of words presented via synthetic and natural speech between dyslexic students and their controls (*matched for Educational level-school grade*);
b) To compare the intelligibility of sentences presented via synthetic and natural speech between two the groups (*dyslexic students versus controls*);
c) To compare the comprehension of texts presented via synthetic and natural speech between the two groups;
d) To seek for correlations between intelligibility and comprehension among students with dyslexia and their matched controls.

2. Participants

The ethical principles of the Declaration of Helsinki were followed and an informed consent obtained from all the participants using the appropriate forms suggested by the World Medical Association.

Forty eight (48) students with dyslexia and eighty three (83) controls without dyslexia had taken part in the present study. Considering comorbidity, the dyslexic students had no other specific learning difficulty apart from dyslexia. The two groups were matched in terms of educational level-school grade and age. Thus the group of dyslexics consisted of thirteen fifth graders (27.1%) and eleven sixth graders (22.9%) of primary school combined with nine first graders (18.8%), ten second graders (20.8%) and five (10.4%) third graders of secondary school. Similarly the group of their matched controls consisted of twenty three (27.7%) fifth graders, eighteen sixth graders (21.7%) of primary school, nineteen first graders (22.9%), fourteen second graders (16.9%) and nine third graders (10.8%) of secondary school. In regard to the educational profile of the controls only those children with an average school performance (in reading, spelling and math’s) were pooled out as participants from the mainstream classrooms (*their selection procedure was carried out by their teachers who had previously looked at their school achievement files*).

All the dyslexic participants came from the data base of two Centers of Evaluation Assessment and Supporting children with Learning Disabilities (named-KEDDY). These two district national diagnostic centers for Learning Difficulties/Disabilities were under the authorization and control of Greek Ministry of Education –sector of Special Education. The selected dyslexic students had passed only the basic diagnostic criteria (***although it is well documented in literature research that selection criteria must be quantifiable as possible for the replication attempts to become meaningful in Greece there is not yet a definite and inviolable agreement and policy between the national and private sectors specialized in diagnosis of dyslexia when it comes to its exclusion criteria. Thus as far as the selection criteria were concerned researchers enlisted students who had* : a) Normal IQ –average or above average determined by the WISC-III, b) at least two years' delay in reading if > 10 years old (*in Greece there is not a formal standardized Reading test that can provide an equivalent reading age, the only existing reading test used in diagnosis of any specific learning difficulty-like dyslexia is the test –A, that provides the expected reading level according to the school grade),* c) normal or corrected vision without any overt emotional or neurological problem prior to commencing schooling, d) use of Greek as native language, and e) an adequate educational opportunity. Participants for the control group came from mainstream schools in the city of Thessaloniki. They had the same educational level-school grade and age (*fifth and sixth graders from primary school and first, second and third graders from secondary school*) with the dyslexics and they did not have any reading problems (*as that documented by their school achievement files-average reading performance*). Both groups of students had to have Greek as their native language. Their participation was thought definite only after the completion and submission of an informed parental consent.

Both groups of students (dyslexics and controls) were asked to indicate if and how often they used assistive technology –mainly screen readers and TTS systems. The frequency of the use of any software was rated on a 3-point scale (none, often, very often). Interestingly, all students did not refer to using assistive technology: neither the dyslexics, nor the control ones adversely dyslexic students stated that they played various computer (i.e., LOL, Farma house, Rally driver, Freeze) more often (on a weekly base), than their normal age counterparts.

3. Materials

A female voice selected in the TTS synthesizer- DEMOSTHeˈNES and used to record the various types of stimuli (words, sentences and texts) both in natural and synthetic speech. DEMOSTHeˈNES is a modular and scalable, multilingual and polyglot TTS system that supports Greek and English with various voices and incorporates advanced speech synthesis methodologies in order to produce almost natural pitch and prosody (Xydas & Kouroupetroglou, 2001a,b, 2006). The speed of presentation was the same for both the natural and synthetic speech (both signals were normalized and balanced at 71dB). All the recordings took place in a recording studio. Regarding the recording of the 200 different words, these were chosen from the list of phonemically balanced Greek words developed by Trimmis et al. (2006); this list includes 200 different disyllable words, separated into four groups of 50 words that are phonemically balanced and of approximately equal difficulty. Preliminary results of this test with native Greek speaking subjects suggested that the word groups were generally equivalent for clinical purposes (Trimmis et al., 2006). In the present study, all the 200 words were used, 100 words recorded in natural speech and 100 words recorded in synthetic speech. Average word lengths were 4.64 and 4.62 characters, respectively. The words in the two word groups did not overlap. All the word stimuli had an open CV/VC or CCV structure.

The twenty (20) sentences were presented after the word list. They were mainly comprised from words from the list. Ten (10) sentences were recorded and presented in natural speech and (10) of them were recorded and presented in synthetic speech. These sentences were mainly consisted of the words used in the first test

The same procedure followed for the two texts *[comprehension subtest of an original standardized A-Test of Reading in Greek population (developed by Panteliadou & Antoniou, 2008*]. They recorded and presented in synthetic and natural speech. The two texts were of a similar level concerning the vocabulary, the morphogrammatical and syntactic structure in use. Their level of difficulty was corresponding to the age range of the group. Thus both texts were neither short (range of words with the title from 97-to-127) nor very long. They just included the right amount of information needed for answering the questions. The seven questions followed per each text (closed response – verification sentences YES/NO), were intended to extrapolate three different kinds of comprehension from listeners'/readers' point of view: the literal, the lexical and the deductive comprehension. The level of validity and internal consistency of the comprehension subtest of the Test-A was reported (r=.80, p<.001) and (a=.845) in Panteliadou & Antoniou, (2008).

A personal computer HP Intel Corei3 was used to implement the test. Microsoft headphones and a Logitech USB desktop microphone were connected to the computer.

4. Procedures

Each student in each group took part in an experiment with three tests. Before each test administered, all students were informed in detail about the procedure that would follow. Students have been informed that they were going to listen to a set of materials produced by both synthetic and natural speech. It became clear to them that after the acoustic presentation of each word, of each sentence they would be simply asked to repeat whatever they heard while after the presentation of the two texts they would be prompted to respond to seven sentences (true or false) at the end of each text.

In the first test, all the students in both groups were asked to identify words, 100 of which were presented in natural speech and 100 of which were presented in synthetic speech. Each student within each group listened to words one by one and repeated them (*open-response format*). After each word was presented, there was a silent period of 3 seconds to allow the student time to repeat it. To avoid any task effect, the presentation of the 100 words in synthetic speech and that of 100 words in natural speech, followed a rotating pattern. Every first and third student (1st +3rd) in each group was presented with 50 words in natural speech followed by the presentation of the 50 words in synthetic. Consequently every second and fourth student (2^{nd} + 4th) in each group was presented with the 50 words in synthetic speech first followed by the presentation of the 50 words in natural speech.

In the second test, all the students were asked to identify 10 sentences produced by a synthesizer (synthetic speech) and 10 sentences presented in natural speech. Similar to the first test, each student within each group listened to the sentences one by one and repeated them (open-response format). There was a silent period of 7 seconds between each of two consecutive sentences to give the participant time to repeat the sentence. The same rotated pattern of the presentation of the stimuli previously employed was also applied here. Every first and third student in each group was presented with the 10 sentences in synthetic speech first followed by the presentation of the 10 sentences in natural speech whereas every second and fourth student in the group had a reversed order of the former presentation of the sentences. The first set of 10 sentences had a *mean* value (6.25) words per a sentence while the second set of 10 sentences had a *mean* of (6.16) words per a sentence (*min*=5, *max*=7 words/per sentence).
In the third test, students listened to the two texts. Both texts were presented in synthetic and natural speech. After their presentation each participant within each group had to verify or reject 14 comprehension statements *(seven statements per text*) that were made up by the researchers. The researchers read the seven sentences to each child after the presentation of each text. The same rotated pattern previously employed for the presentation of the words and sentences was also applied here. Thus, every first and third student in each group, had heard text one (1) in a synthetic speech and text two (2) in a natural speech. Conversely every second and fourth student in each group had heard text one (1) in a natural speech and text two (2) in a synthetic speech.

The entire procedure was conducted by the researchers, and ultimately all the participants' answers were audiotaped, transcribed into Greek, organized, reviewed for errors, and analyzed using SPSS statistical analysis software. The data collected and analyzed by the researchers separately. A comparative introspection of the results followed as both researchers had to be absolutely sure that had followed the same way of analysis. The qualitative categorization of the participants' errors *(only for word intelligibility test*) was based on phoneme error patterns (Papadopoulos, Argyropoulos, & Kouroupetroglou, 2008). The phoneme error pattern consisted of categories of phonological type of errors. Phonological-type errors are those that change the auditory representation of the word (see table 1 for a list of all the categories). An additional quantitative analysis had taken place for both synthetic and natural speech calculating simply the total number of errors made and the total number of words and sentences correctly identified by both groups in intelligibility test. The total number of error answers for the comprehension test was also provided for both texts presented in either speech condition.

An attempt was made to minimize a learning effect: Each participant was examined alone; none heard the words before the tests, and the synthetic and natural-female voice for stimuli was different. See table 1.

Table 1: Categories of phonological-type of errors (PTE)

Categories	Phonological type of errors
A	Accentuation (accent)
B	Phoneme substitution (first sound of the words)
C	Phoneme substitution (middle and last sound of word)
D	Addition of a phoneme (fist sound of the word)
E	Addition of a phoneme (middle and last sound of word)
F	Combination of the following: 1. Omission of more than one phoneme in the word 2. Addition of more than one phoneme in the word 3. Wrong rendering regarding accentuation combined with phoneme substitutions or omissions
G	Omission of the whole word or rendering of a different word

5. Results

The forty eight students with dyslexia and the eighty three controls matched for *educational level*-school *grade and age* without dyslexia participated in the study. Twenty seven boys (56.3%) and twenty one (43.8%) girls comprised the dyslexic group whereas forty six boys (55.4%) and thirty seven girls (44.6%) comprised the group of matched controls. Regarding the age variable the age range for the dyslexic group was (*M*=12.22, *SD*=1.43). The age range for the controls was (*M*=12.13, *SD*=1.33).

The total mean number of words and sentences correctly identified in the intelligibility test was estimated for both groups of students (dyslexics versus grade/age matched controls) in both natural and synthetic speech condition. The total mean error number for words and sentences incorrectly identified in the intelligibility test and the total of error answers in text comprehension were also provided (See table 2).

Table 2: Mean accuracy levels for intelligibility and error values for comprehension in both natural and synthetic speech for both groups

	Natural Speech		**Synthetic Speech**	
	Dyslexics	**Educational level controls**	**Dyslexics**	**Educational level controls**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Correct words	**95.90 (4.15)** Min-max 81-100	**99.13 (1.12)** Min-max 96-100	**80.48 (6.93)** Min-max 63-98	**86.08 (4.26)** Min-max 74-95
Correct sentences	**9.23 (1.05)** Min-max 6-10	**9.83 (0.64)** Min –max 5-10	**8.40 (1.16)** Min-max 6-10	**9.17 (0.83)** Min-max 7-10
Error words	**4.10 (4.15)** Min-max 0-19	**0.87 (1.12)** Min-max 0-4	**19.52 (6.93)** Min-max- 2-37	**13.80 (4.17)** Min-max----5-26
Error sentences	**0.77 (1.05)** Min-max 0-4	**0.17 (0.64)** Min-max 0-5	**1.60 (1.16)** Min-max---0-4	**0.83 (0.83)** Min-max 0-3
Text error answers	**1.96 (1.12)** Min-max 0-5	**1.67 (1.06)** Min-max 0-4	**2.40 (1.34)** Min-max 0-6	**1.78 (1.03)** Min-max 0-4

A three-way mixed design ANOVA analysis was carried out with two-between subjects factors and one repeated measure (within–subject factor). The between subjects factors were the educational level group (*fifth and sixth graders of primary school versus first, second and third graders of secondary school - five different school grades*) and the type of group (dyslexics versus age matched controls). The within subjects factor was the speech type (natural versus synthetic speech). As far as the test of word intelligibility was concerned, the analysis revealed a significant main effect for speech type [$F(1,127)=643.896$, $p<.001$], a significant main effect for group type (*dyslexics versus controls*) [$F(1,127)=77.009$, $p<.001$], a significant main effect for educational level group (*students of primary school versus students of secondary school*) [$F(1,127)=7.870$, $p<.01$] and two significant interactions –a) for speech type and group [$F(1,127)=4.430$, $p<.05$] and b) for speech type and educational level group [$F(1,127)=6.737$, $p<.05$] respectively. Dyslexics ($M=95.90$) and their matched controls ($M=99.13$) had identified more accurately words presented in natural speech compared to when words presented in synthetic speech [(Dyslexics $M=80.48$) and (Controls $M=86.08$)] (see table 2). The same trend of results stood for their mean error values in both speech conditions. Interestingly concerning the main effect of group type, the controls had produced more correct words ($M=99.13$) than the dyslexic students ($M=95.90$) did when words presented in natural speech and far more correct words ($M=86.08$) than dyslexics

(*M*=80.48) did when words presented in synthetic speech. The significant interaction between speech type and group [$F(1,127)=4.430$, $p<.05$] supported further the former results (see figure 1). Thus it was shown that not only both dyslexics and their matched controls had performed far better in natural speech, recognizing more correct words, as that compared to their performance in synthetic speech but also that the controls had recognized more correct words than dyslexics did in both speech conditions.

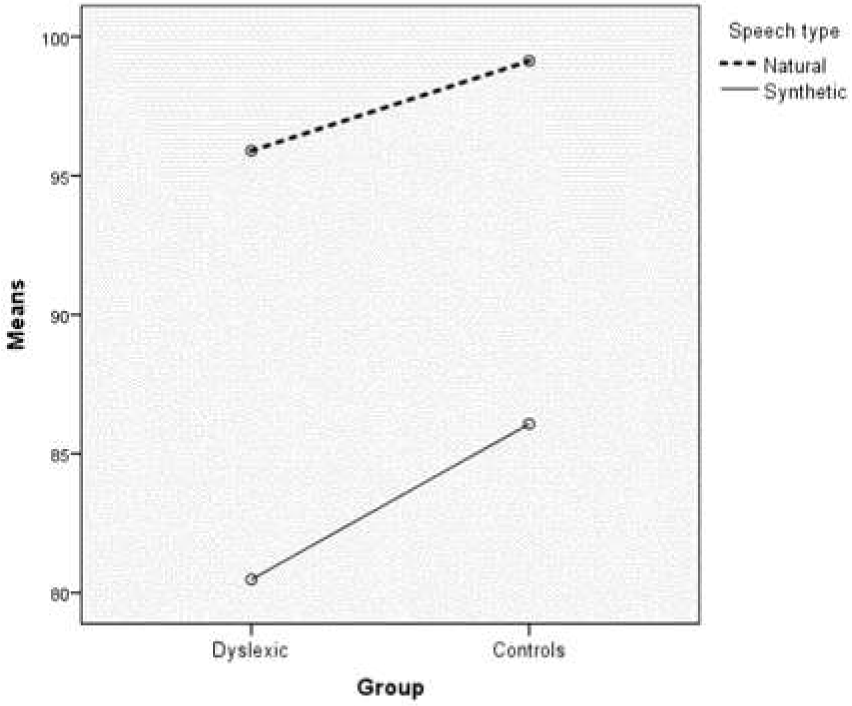

Figure 1: Word intelligibility in natural and synthetic speech in relation to group (dyslexics versus their Educational level controls)

In relation to the significant interaction [$F(1,127)=6.737$, $p<.05$] between speech type and educational level group (*students of primary versus students of secondary school*), it seemed that students of secondary school had performed better recognizing more correct words in synthetic speech than their counterparts of primary school did in the same speech condition(see figure 2).

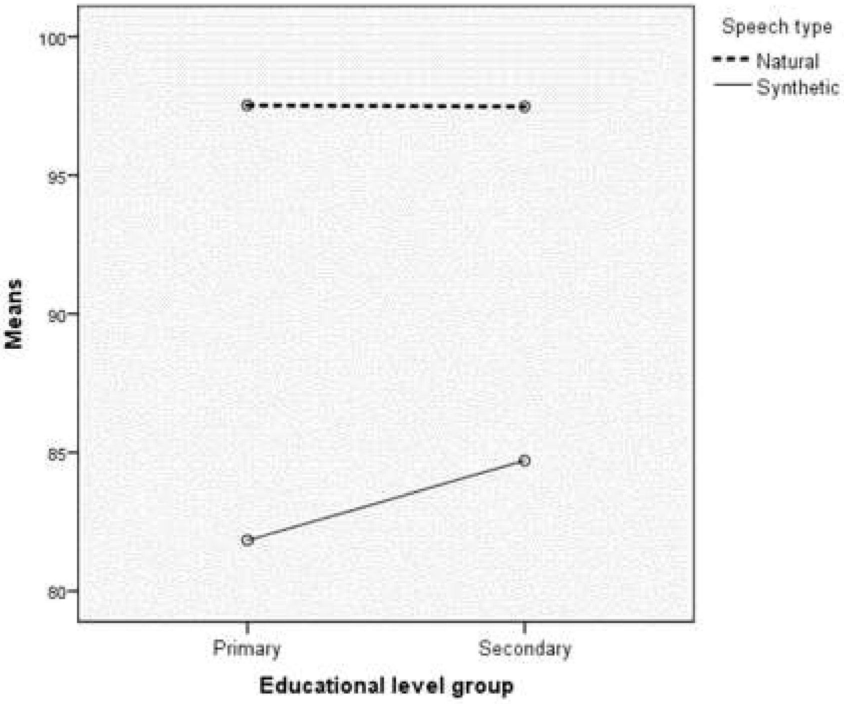

Figure 2: Word intelligibility in natural and synthetic speech in relation to educational level group (students of primary school versus students of secondary school)

As far as the sentence intelligibility was concerned the analysis revealed a significant main effect for speech type [F(1,127)=60.176, p<.001], a significant main effect for group (dyslexics versus their matched controls) [F(1, 127)=31.171, p<.001] and a significant main effect for educational level group (*students of primary school versus students of secondary school*) [F(4, 127)=17.779, p<.001] (see table 2). No other significant interactions were observed. Hence, dyslexic students (*M*=9.23) and their matched controls (*M*=9.83) had produced significantly more correct sentences when these were presented in natural speech compared to their presentation in synthetic speech [Dyslexics (*M*=8.40) and controls (*M*=9.17)]. Moreover the controls had recognized more correct sentences in both natural (*M*=9.83) and synthetic speech (*M*=9.17) than their dyslexic counterparts did [(*natural speech-M*= 9.23) and (*synthetic speech-M*= 8.40)] respectively. Similar results have been observed for the mean error values in sentence intelligibility test. Given the significant main effect for educational level group (*students of primary school versus students of secondary school*), it seemed as if the older the participants in both groups the better their performance was in both speech conditions in sentence intelligibility test. The interesting and closer to significant interaction between speech type, group (*dyslexics versus controls*) and educational level group (*students of primary versus of students of secondary school*) [F(4, 127)=3.859, p<.052)], could elucidate further the way by which both groups of participants, based on their educational level, had performed in natural versus synthetic speech.

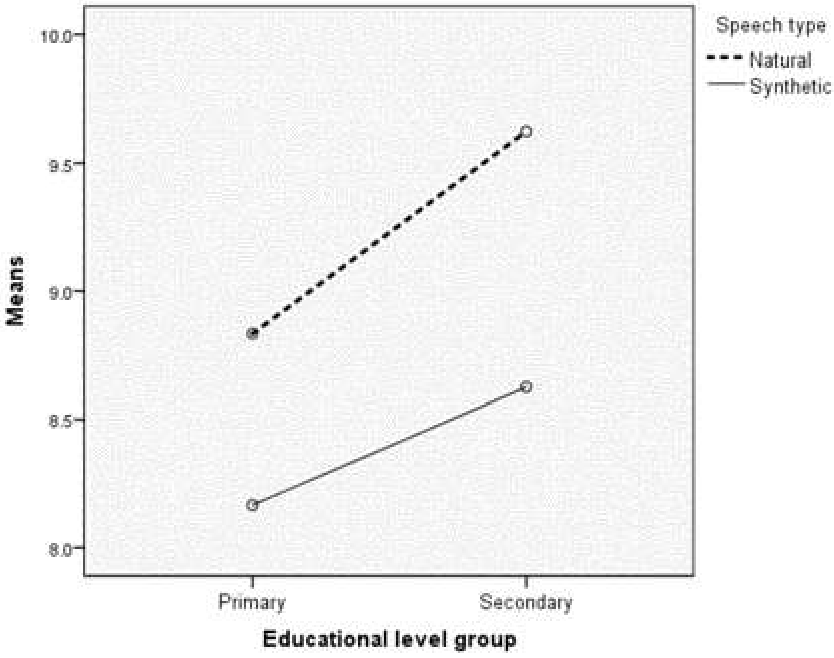

Figure 3: The interaction for speech type and educational level group for dyslexics

In figure 3, it is clearly seen that dyslexic students of secondary school achieved a better performance recognizing more correct sentences in both speech conditions than the dyslexic students of primary school did respectively. Furthermore dyslexic students of secondary school appeared to have had a better performance in recognizing more correct sentences when those were presented in natural than in synthetic speech. Similarly, observations have been noticed for dyslexic students of primary school, where the sentences presented in natural speech seemed to have claimed higher accuracy values compared to their presentation in synthetic one.

In figure 4 the control students of secondary school seemed to have performed better recognizing more correct sentences in both speech conditions than the control students of primary school did respectively. Furthermore the control students of secondary school appeared to have produced higher accuracy values recognizing more correct sentences presented in natural than when these presented in synthetic speech. Likewise the control students of primary school seemed to have produced higher accuracy values for sentences presented in natural speech compared to the sentences presented in synthetic one.

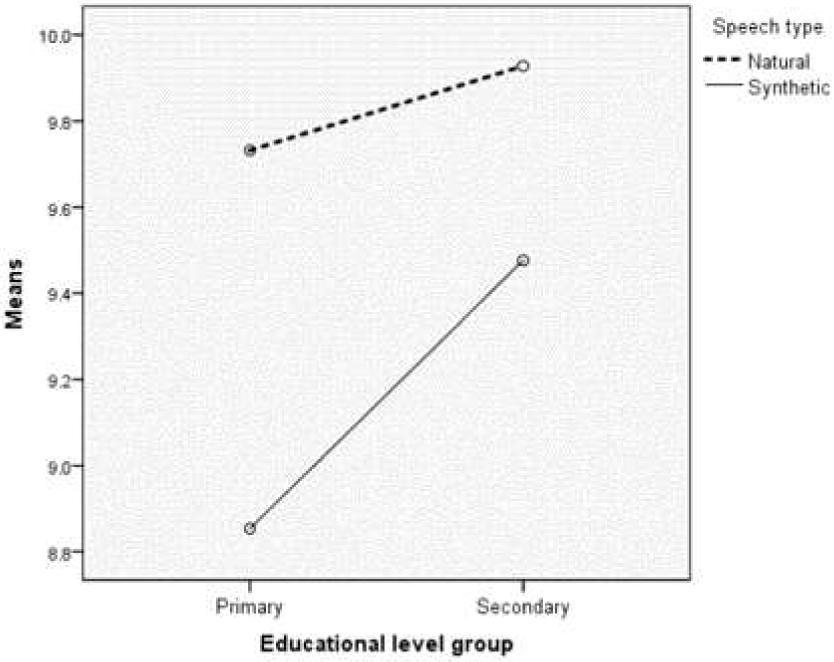

Figure 4: The interaction for speech type and educational level group for controls

Finally in relation to the text comprehensibility there was a significant main effect for speech type (natural versus synthetic speech) [F(1,127)=4.320, p<.05], a significant main effect for group [F(1,127)=8.540, p<.01] and a significant main effect for educational level group [F(1,127)=6.599, p<.05]. Both dyslexics and their controls had performed far better in text comprehension test when texts presented in natural speech [(Dyslexics *natural M*=1.96) and (controls *natural M*=1.67)] than when texts presented in synthetic speech [(Dyslexics *synthetic M*==2.40) and (controls *synthetic M*=1.78)]. Moreover the controls had produced fewer error answers, higher levels of text comprehension for both speech conditions (*natural speech-M*=1.67) and (*synthetic speech-M*=1.78) compared to what dyslexics did [(*natural speech M*=1.96) and (*synthetic speech M*=2.40)].

The phonological types of errors were estimated next in the intelligibility tests for both groups in both speech types (see table 3).

Table 3: Phonological type of Errors in the intelligibility test
for both groups and in both speech types

	Natural Speech		**Synthetic Speech**	
	Dyslexics	**Educational level controls**	**Dyslexics**	**Educational level controls**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Categories of Phonological errors				
A. Accentuation errors	0.27 (0.64)	0.07 (0.26)	2.42 (2.23)	1.84 (1.78)
B. Substitution of phonemes				
First sound	1.90 (1.72)	0.39 (0.65)	3.25 (2.32)	2.02 (1.33)
C. Substitution of phonemes				
Middle sound	0.29 (0.50)	0.12 (0.36)	0.94 (1.11)	0.36 (0.59)
Last sound	0.25 (0.60)	0.00 (0.00)	0.19 (0.44)	0.04 (0.18)
D. Addition				
First sound	0.56 (0.82)	0.14 (0.35)	1.81 (1.33)	1.43 (1.50)
Middle sound	0.00 (0.00)	0.00 (0.00)	0.13 (0.39)	0.11 (0.31)
Last sound	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
E. Omissions of phonemes				
First sound	0.10 (0.30)	0.01 (0.11)	0.19 (0.44)	0.05 (0.21)
Middle sound	0.04 (0.20)	0.00 (0.00)	0.08 (0.27)	0.04 (0.18)
Last sound	0.02 (0.14)	0.00 (0.00)	0.04 (0.20)	0.02 (0.15)
F. Omission of more than one phoneme in the word	0.06 (0.24)	0.00 (0.00)	1.94 (1.79)	1.13 (1.47)
G. Omission of the whole word or rendering of a different word	0.85 (2.55)	0.20 (0.46)	8.35 (6.01)	7.23 (4.12)

As we can see in table 3, it was obvious that dyslexic students had made more phonological type of errors than their matched controls in the intelligibility test (*for words/ and sentences*) in both speech conditions. Furthermore the dyslexic students had made more phonological type of errors when identified words presented in synthetic speech than when they identified words presented in natural speech. The categories of errors that claimed the higher error means in synthetic speech were: the accentuation (*M*=2.42), the substitution of the first sound (*M*=3.25), the addition of the first sound (*M*=1.81) and the omission of more than one phoneme in the word (*M*=1.94). Similarly dyslexics appeared to have a higher mean error values (*M*=8.35) than their controls did for the category omission of the whole word when tried to identify words presented in the synthetic speech.

A few significant correlations were also carried out. For the group of dyslexics two statistically significant positive correlations were observed: the first one was between the mean number of sentences correctly identified in natural speech and the mean number of words correctly identified in the natural speech (r=.296*, p<.041). The second one was found between the mean number of sentences correctly identified in natural speech and the mean number of words correctly identified in synthetic speech (r=330*, p<.022). The mean number of sentences correctly identified in synthetic speech was significantly correlated with the mean number of words correctly identified in the synthetic speech (r=.403**, p<.004).

For the group of controls there was a significant correlation between the mean number of words correctly identified in natural speech and the mean number of words correctly identified in synthetic speech (r=.224*, p<.042). The expected and highly significant correlation was the one between the mean number of words correctly identified in natural speech and the mean number of sentences correctly identified in the same speech condition (r= 303**, p<.005). Furthermore the mean number of sentences correctly identified in synthetic speech was found to be significantly correlated firstly with the mean number of words correctly identified in natural speech (r=.248*, p<.024) and secondly with the mean number of sentences correctly identified in natural speech (r=.235*, p<.032). Lastly the mean number of error answers for the text presented in natural speech was found to be positively correlated with the mean number of error answers for the text presented in synthetic speech (r=.246*, p<.0025).

6. Discussion

Taken under consideration the small number of studies investigating the use of speech synthesizers (TTS) by individuals with dyslexia and the none existing research in intelligibility and comprehension of synthetic speech by Greek dyslexics, the current study attempted to contribute further to the understanding of issues associated with intelligibility and comprehension of dyslexics versus their school grade matched controls when acoustic stimuli presented in synthetic versus natural speech.

Regarding the first aim of the study, Greek dyslexics and their controls were found to have performed significantly better in intelligibility test when words presented in natural speech rather than when words presented in synthetic speech. Their word accuracy levels were higher in natural speech [(*dyslexics M*=95.90), (*controls M*=99.13)] compared to their accuracy levels in synthetic speech [(*dyslexics M*=80.48), (*controls M*=86.08)]. Similar results were revealed concerning their mean error values in natural speech versus synthetic speech condition. Both dyslexics and their controls had made far less word errors in intelligibility test in natural speech [(*dyslexics M*=4.10), (*controls M*=0.87)] than they both did when words presented in synthetic speech [(*dyslexics M*=19.52), (*controls M*=13.80)]. Such a finding was important for two reasons: Firstly because it was in line with several other studies in people with and without disabilities (Duffy & Pisoni, 1992; Koul & Allen, 1993; Papadopoulos Koutsoklenis, Katemidou, & Okalidou 2009), where it was found that intelligibility of natural speech was significantly greater than that of synthetic one and secondly because both groups behaved quite similarly in recognizing the words' segments in both speech conditions (natural versus synthetic). At this point someone could naively suggest that synthetic speech suffered more degradation in this test condition for both groups of participants. However, it remains open to question for future research in the field of whether results as such obtained with synthetic speech may be generalized to speech perception.

The significant interaction between speech type and group seemed to have provided a support to the former results. Greek dyslexic students were found to have identified fewer correct words (*M*=95.90) presented in natural speech than their controls (*M*=99.13) did and even far less correct words (*M*=80.48) when words presented in synthetic speech than their controls (*M*=86.08) did respectively. Regarding the second significant interaction *between speech type and educational level* group, it seemed that the older students in both groups are, the better performance they have, identified more correct words in the synthetic speech than the younger students, did. Such pattern of result seemed to imply that their performance had been possibly subjected to an age maturation effect.

As mentioned above the dyslexics' performance in word intelligibility was more impaired in synthetic speech than it was in natural, was in line with the very few studies in the field that compared performance of dyslexic and control participants at a categorical perception task in synthetic speech (Bloomert and Mitterer 2004; De Weirdt, 1988; Godfrey, Syrdal-Lasky, Millay, & Knox 1981; Steffens, Eilers, Gross-Glen, & Jallad, 1992). Although the methodology employed by these studies was not directly the same with the present one, researchers reported that dyslexics were less consistent than controls in identification of the synthetic continua and had difficulties in identifying phonetically similar, though phonologically contrastive, synthetic syllables. Such results suggested that speech categories may be, for unknown reasons, broader and less sharply separated in reading by dyslexics than by normal children. Likewise in the present study it might have been the case where dyslexics were less able to adapt to the range of word stimuli they hear in synthetic speech and perhaps be poorer than controls in recognizing words in synthetic speech. Considering our dyslexics' difficulties in identifying words in synthetic speech led us to suggest with extreme caution though that they might have been recognizing speech sounds/phonemic categories less sharply than their controls.

The fact that dyslexics had made more phonological type of errors than their controls did when identified words in synthetic speech compared to natural one could offer a further support to the former suggestion. The categories of errors that claimed the higher error means in synthetic speech were the accentuation, the substitution of the first sound, the addition of the first sound and the omission of the whole word. These results were quite like those which have been observed in study by Papadopoulos, Koutsokenis Ketemidou and Okalidou (2008) where their visual impaired participants also found to have made significantly more phonological type of errors identifying words and sentences in synthetic speech than in natural. Regarding the former similarity, future research should be carried out in in the field in order to elucidate further whether Greek dyslexics of various educational levels have a deficit in the recognition/ identification of acoustic stimuli drawing a distinct line between words with and without phonological similarity. If such a deficit is present, it would be observed with synthetic as well as natural speech.

Concerning the second aim of the present study was concerned, both groups of participants were found to have shown higher accuracy values when sentences were presented in natural speech than when these presented in synthetic speech. The controls had recognized more correct sentences in both natural and synthetic speech [(*natural M*=9.83) *and* (*synthetic* M=9.17)] compared to what their dyslexic counterparts did respectively [(*natural M*=9.23 *and (synthetic M*=8.40)]. Such a finding was in line with studies by Koul & Allen, 1993 and Papadopoulos et al., (2009) where it was also observed that their participants had shown greater sentence intelligibility for natural speech than for synthetic speech. Considering the significant main effect for educational level group, it seemed that the older students in both groups are the better performance they have in sentence intelligibility test in both speech conditions. The closer to significant interaction between speech type, group and educational level group have showed that both dyslexics and their matched controls -students of secondary school-might have recognized more correct sentences in both speech conditions than their counterparts, of primary school did. No matter the distinct impact of the age maturation effect on the performance of both groups in both speech conditions, the natural speech consistently claimed the higher accuracy levels for sentence intelligibility compared to the synthetic one. Future research in the field is needed before someone comes to any conclusions regarding the presence of age maturation effect on the performance of both groups in both speech conditions. If the researchers had controlled better the characteristics of both groups (IQ level, reading age, academic achievement) in the present study perhaps it might have been easier for them to suggest firmly that the older the participants the better and even the more accurate their performance was in the sentence intelligibility test.

Despite to what had been previously discussed the fact that the controls had a better performance than the dyslexics in sentence intelligibility in both conditions, remained quite an interesting result that opposed to what a study by Papadopoulos Argyropoulos, and Kouroupetroglou (2008) found for a number of reasons. Researchers had also noticed that their visual impaired individuals responded correctly and significantly more frequently than their sighted peers in a sentence intelligibility task in synthetic speech. That was because in Greek language with a different structure to English (multisyllabic structure for words) is much easier for a native listener to extract the meaning from other parts of words or sentences when certain parts of them are not intelligible in synthetic speech. Thus visual impaired individuals seemed to have exploited the nature of Greek language in better way than their controls did in synthetic speech. Unexpectedly our dyslexics did not behave in the same way. Without being biased that firstly the two studies had a few differences in method part and secondly that the participants groups had different learning difficulties and age range, it was still interesting that dyslexics in the present study did not manage to extract the meaning from other parts of words or sentences when certain parts of them were not intelligible in synthetic speech, at least in better way than their controls did. Perhaps the fact that our dyslexics did not have the same experience level with the TT Systems as the visual impaired individuals had in Papadopoulos et al., (2008) study, might have negatively contributed to the results. Moreover we should notice here that in Greece and especially in KEDDY the selection criteria of the dyslexics are not as strict and tight as in the rest of European countries. They are usually diagnosed on the grounds of their IQ difference in relation to both their general academic achievement and their low levels of reading performance on a standardized reading test by Panteliadou and Antoniou, (2008). Consequently risks of comorbidity and differences within the educational profile of the very same group of dyslexic participants in the present study could not be totally avoided. Presumably a future research (*as in studies by Duffy & Pisoni, 1992; Reynolds & Fucci, 1998; Reynolds & Jefferson, 1999*) in the field of sentence intelligibility controlling for parameters associated with the selection of dyslexics versus controls (*IQ level, reading age, educational level, academic achievement*) and using online measures such as response latencies to both highly and less predictable sentences might reveal a different set of results and even assess better the cognitive load placed on the individuals by synthetic speech.

In addition, regarding the third aim of the study, both dyslexics and controls were found to have better performance in comprehension ability when texts presented in natural speech compared to when those were presented in synthetic speech. This finding was partially in line with studies (Duffy & Pisoni, 1992; Reynolds & Fucci, 1998; Reynolds & Jefferson, 1999) where typical listeners were found to have significant differences in their comprehension abilities in synthetic speech, compared to natural one. Their comprehension of narratives was faster, easier and more accurate when materials were presented in natural speech, rather than in synthetic speech. Not quite differently both our groups of students seem to have achieved greater cognitive effort in processing texts presented in synthetic speech compared to texts presented in natural speech. The fact that the controls were found to have performed better in text comprehension than the dyslexics had in both speech conditions should not be treated lightly leading to the suggestion that dyslexics might have been affected more by the novel acoustic stimuli, which provided by the synthetic speech. Since Koul, (2003) has stated as far as concern the quality of synthetic speech on comprehension, that several factors can affect the comprehension outcomes such as complexity of the task, the presence or absence of a coherent context, the rate of presentation and the speech method, further research is needed before any assumption is offered for the differences, that have been previously observed between dyslexics and normal control subjects. This research should incorporate all the factors that might contribute to differences between the groups such as speech quality, overall intelligibility of the input signal, different level of difficulty of the passage, different educational levels, different levels of experience with the TSS systems, and more sensitive response measures than the multiple choices or the true of false response.

To sum up, the number of correlations carried out, revealed that for both dyslexics and age matched controls the mean number of words correctly identified in natural speech was positively correlated with the mean number of sentences correctly identified in the same speech condition. Furthermore, for both groups the mean number of words that correctly identified in synthetic speech was positively correlated with the mean number of sentences correctly identified in the same speech condition. In other words, it seemed that for both groups the higher level of word accuracy in both speech conditions it could underpin higher levels of sentence accuracy in natural and synthetic speech as well.

6.1 Practical implications

Acknowledging that the present study had shown different levels of performance between Greek dyslexics and their controls, regarding the intelligibility and text comprehensibility in synthetic versus natural speech, we would like to notice that our results could not undermine the practical use of Text to speech systems (TTS) and their applications in the Augmentative and Alternative Communication of people with learning disabilities. On the contrary, we believe that the text-to-speech systems might and could serve as a scaffold, for students, with reading difficulties helping them to master reading tasks that they may not have been able to do on their own. Furthermore, and most importantly, the use of text-to-speech systems could provide with former modifications the extra time that is needed, guided practice, and supplemental instruction that students with reading disabilities require to be more successful in the reading process.

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