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The interaction of language and music: a psycholinguistic approach for a shared pitch mechanism (?)

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Abstract

Over the last decades there is an increasing interest in the comparative research between language and music. A significant amount of studies has focused on the shared underlying processes in both domains (e.g. Patel et al., 1998; Patel, 2003; Slevc et al., 2009; Fedorenko et al., 2009, Jiang et al., 2010). While evidence is contradictory (e.g. Peretz, 1993; 2008; Peretz et al., 1994; Peretz & Coltheart 2003; Chen et al., 2018), no prior research denies the apparent similarities of language and music with respect to the structural rules and principles required for the linguistic and musical adequacy. Following previous claims that intonation shapes the word boundaries eliminating sentence ambiguities (Papangeli & Marinis, 2010), the present research thesis proposes a self-paced reading-listening experiment to investigate whether musical pitch can substitute the use of intonation in ambiguous contexts. As a result, it would indicate that non-linguistic acoustic cues, such as music pitch, may contribute to language comprehension, specifically to disambiguation. This is expected to become evident through the comparison of reading times across ambiguous and non ambiguous (control) conditions, under high, neutral and low musical pitch exposure. The results show that although there are indications that high musical pitch exposure facilitates processing of the ambiguous sentences, it did not reach significance, rejecting the experimental hypothesis. However, the present thesis concludes that language and music might share a common pitch mechanism. Such findings could further contribute to our understanding of the brain organization and the underlying shared general cognitive mechanisms. Lastly, it could also be departure for treatment approaches from unimpaired domains to impaired ones in clinical cases such as, aphasia and amusia.

Keywords: *Language, Music, Intonation, Pitch, Shared mechanism.*

1. Introduction

When a reader or a hearer processes a sentence like, *Yesterday while they were recording the violins were sounding out of tune*, they come up against a temporal structural ambiguity. Specifically, the constituent *the violins* is initially interpreted as the object of the optionally transitive verb *record*. Immediately afterwards, once the reader-hearer analyses the second VP of the sentence (*were sounding*), they realize that the preceding element (*the violins*) is eventually the subject of that VP and the sentence is disambiguated. Following prior research in Greek temporal ambiguity, the parsing analysis of such type of sentences has been attributed to two complementary views. The *late closure principle* that is referred to a preference to attach upcoming constituents (Papangeli & Marinis, 2010) and the claim that if *the violins* was attached to a new thematic domain, extra processing costs would be demanded (Papadopoulou & Tsimpli, 2005).

In psycholinguistic research, the processing preference of a syntactic analysis that later on is proved inadequate is known as *garden path effect* (Frazier, 1978)[1]. The ambiguity that is caused can be resolved with the use of intonation. For instance, if there is an intonational emphasis on the first VP (*were recording*), the hearer is motivated to interpret directly *the violins* as the subject of *were sounding* (see sentence 1 for a thorough view). Past research that encourages this proposal, suggests that intonation indeed shapes the word boundaries, eliminating such sentence ambiguities in Greek, as shown through the response times in a self-paced listening task (Papangeli & Marinis, 2010). The present thesis investigates whether non-linguistic signals, such as musical tones, can contribute to language comprehension, specifically to disambiguation, indicating that intonation and musical pitch might share a common underlying process. To begin with, I will outline some general commonality between linguistic and musical cognition in order to better substantiate the hypothesis that musical tone can carry out the same function as intonation for the purposes of disambiguating.

1.1 General commonalities between language and music

From a psycho/neuro-linguistic point of view, past research has shown that two arbitrary systems give human language its major expressive power: a *mental lexicon* and *a mental grammar* (Ullman et al., 1997). The former refers to a conventional sound-pairing system that stores lexical information, while the latter to a dynamic, rule-generative system that combines lexical information (e.g. words) in order to create a(n) (infinite) number of phrases and sentences (Chomsky, 1965; De Saussure, 1959; Pinker, 1994). According to the traditional generative grammar theory, the mechanisms that perform those processes are linguistically autonomous from other cognitive faculties (Chomsky, 1957; Pinker, 1994; Chomsky, 1991; Jackendoff 1997) with respect to the psychological computations and their neural architecture (Molino, 2000). Nevertheless, with simple analogical thinking, music might also have two analogous operational systems: the storage of musical notes and a mental, combinatorial, rule-generative grammar that also have the capacity to create a(n) (infinite) number of musical progressions respectively. It might be therefore important

[1] For a general review on garden path effect, see Pickering & van Gompel, 2006.

to distinguish the common underlying processes between language and music from the distinct representational outcomes that they display.

An aspect of human cognition that might support that claim further may come from the field of implicit learning. Past artificial language learning studies have shown that after low input complexity exposure, learners are only able to recognize familiar items, as a result of memorization, displaying insignificant generalization rates (learning). However, once input complexity increases, they are better able to generalize novel instances that obey the phonotactical rules of the exposed artificial grammar, rather than memorizing specific items. Thus, learning seems to have a strong correlation not only with input complexity, but also with the encoding capacity that triggers memorization or generalization (see Radulescu et al. (2018) for a general overview on language AGL). Similarly, prior artificial music learning studies in musically untrained participants have shown analogous performances (see Loui & Wessel, 2006; 2008; Loui et al., 2010; Loui, 2012, for a general overview on music AGL). Specifically, after low input exposure, it seems that learners are able to recognize familiar notes, but their generalization rates are insignificant. However, once the exposed musical sequences increase, the generalization rates are also significantly higher. As it was the case with language learning, input complexity and encoding power have a decisive role for music learning too. Comparing the evidence from the domain of language AGL with the music AGL, it seems that increasing input complexity, either set of melodies or set of strings, leads to grammar learning of the underlying regularities. Additionally, in the domain of language, Radulescu et al., (2018) found that generalization rates were not infinitely increasing as a function of the increased complexity, reporting a ceiling effect that was attributed to the limitation of the channel capacity (encoding resources). Although researchers of the music AGL studies did not report any similar effect, it was apparent that the generalization rates were not also infinitely increasing for music as a function of the increased complexity of the musical sequences. In conclusion, it is probably clear that there are indications for a domain-general learning mechanism between language and music.

Another aspect of human cognition that might also support the idea of shared mechanisms between language and music may come from behavioral comparative studies related to syntactic processing. For instance, Slevc et al., (2009) and Fedorenko et al., (2009), found that the simultaneous structural integration demands in language and music led to longer processing times and low comprehension accuracies in a self-paced reading and a listening task respectively. More specifically, the former tested whether reading times would be even longer with the simultaneous musical syntactic processing demands in temporarily ambiguous sentences. They also tested whether semantic expectancy (priming) demands in language and music, would also lead to analogous results. The authors reported that reading times in the critical region of ambiguity were even longer under musical syntactic violations (out of key notes), compared to the condition where there was no musical syntactic violation (in key). This effect was not found in similar sentences where unexpected words and unexpected musical timbre displayed simultaneously. In turn, this led to the hypothesis that language and music interact at a syntactic level, but not at a semantic one. Similarly, Fedorenko et al., (2009) also investigated whether simultaneous structural integration demands in both domains would lead to longer listening times and low comprehension accuracies. In their experiment, as opposed to ambiguous and non-ambiguous sentences, they used sentences with non-local and local dependencies, expecting that the first ones would demand more syntactic processing resources, compared to the sentences with local dependencies that are expected to have easier process. At the same time, they used musical notes either with musical syntactic violation or without. As it was the case in the experiment of Slevc et al., (2009), they were expecting that the simultaneous syntactic integration demands would lead to limited available syntactic processing resources, therefore, longer listening times and low comprehension judgments. In their experiment, they also used acoustical anomalous stimuli (increasing loudness), to check whether a potential effect would be due to simple sound distraction. The results revealed that accuracy judgments in non-local dependencies was significantly lower when musical stimuli also demanded more structural processing resources (out of key), in comparison with the in key musical manipulation of the same sentences[2]. This effect was not found with acoustical anomalous musical notes. Thus, it seems that language and music overlap under simultaneous structural integration demands, but not under simultaneous semantic and acoustical deviant expectancies.

Both studies linked their evidence with a prior well known hypothesis of the field, called the *Shared Syntactic Integration Resource Hypothesis (SSIRH)* of Patel, (2003), which states that the cognitive and neural resources of a shared syntactic mechanism among distinct domains should lead to competition of the resources. In behavioral terms, this would lead to longer processing times under simultaneous syntactic processing demands. In contrast, if the syntactic mechanism is not common, such competition of the resources would not be expected, therefore, the response times would be faster. This hypothesis has strong support from neuroimaging studies that found activation of the P600 component, during the integration of syntactically difficult structures of language and music (Patel et al., 1998), as well as from subsequent functional neuroimaging studies that found cortical activations in and around associative language brain areas, such as Broca's area and in the right brain homologue, through musical manipulations (Stromswold et al., 1996; Koelch et al., 2002; Levitin & Menon, 2003; Maess et al., 2001; Tillman et al., 2003).

In sum, it seems that although language and music are two different functions of the human cognition, the underlying processes display some commonalities, as shown in comparative syntax-related studies. Taking everything into account, the representational systems are autonomous (domain-specific), while the mechanisms that are involved during the initial stages of processing information might be shared (domain-general) among domains such as language and music. As stated in the introduction of the present paper, another mechanism that is suggested to display an underlying shared process between language and music is pitch.

1.2 Intonation & Pitch

From a theoretical perspective, *Homo sapiens* seems to be the only species equipped with adequate language and music capacities. The smallest units in both domains are physical sound entities that result from the sound processing information system. The sound pairing of consonant and vowels produces language in its primary form (and prosody), while the sound pairing between pitches and timbres creates the basis for music (Tomasello et al., 2003; Patel, 2010). In both cases, there is a common physical process of pairing sound information that involves pitch. That makes pitch one of the

[2] Note that in the experiment of Fedorenko et al., (2009) the results are based only on the comprehension accuracies of the questions that followed the experimental sentences due to a technical error that researchers faced during the analysis of the listening times.

most salient features of sound perception which has the property to be classified in scales from low to high (Randel, 1978; Patel, 2010). In language, those properties lie behind intonational contrasts that have the momentum to change the meaning of an utterance. In music, pitch contrasts structure a musical system and as a result the melodicity, which also have the dynamics to change emotions respectively (Patel, 2010).

Taking into account the claims that language and music display some commonalities (Patel et al., 1998; Patel, 2010), the studies related to the shared structural integration mechanisms between language and music (Patel, 2003; Slevc et al., 2009; Fedorenko et al., 2009), as well as the evidence that intonation resolves temporal ambiguity in Greek (Papangeli & Marinis, 2010), it would offer a better understanding in the field of comparative research between language and music to test the hypothesis whether high musical pitch can substitute intonation, contributing to language comprehension. As a result, it would indicate that language and music may interact not only at a syntactic integration level, but also at a sound processing information one. Therefore, the following research question is addressed: *Do intonation and musical pitch share an underlying process?* Conducting a self-paced reading-listening experiment, it is attempted to test whether high musical pitch can substitute the use of intonation in ambiguous contexts. This is expected to become evident through the comparison of reading times across ambiguous and non ambiguous (control) conditions, under high, neutral and low musical pitch exposure. Specifically, if high musical pitch exposure does not reveal facilitation processing of the ambiguous sentences, as intonation does so, the null hypothesis is confirmed. In contrast, if high musical pitch facilitates processing of the ambiguous sentences and there is no distraction from low pitch, the null hypothesis is rejected. Thus, in that case, the big picture of the proposal would be that language and music might share a common pitch mechanism. Such findings, could contribute to our better understanding of the human cognition, the organization of the brain and the underlying shared general cognitive mechanisms. Potentially, it could also be departure for treatment approaches from unimpaired domains to impaired ones in clinical cases such as, aphasia and amusia.

Regarding the organization of the present thesis, the next section is devoted on an interdisciplinary literature review. Section 3, states the methodology along with the experimental information, while the remainder of the paper discusses the results and their conclusions.

2. Literature review

The present section states an interdisciplinary literature review regarding the association of pitch between language and music. The evidence comes from Psycholinguistics, Psychology, Neuroscience and Musicology research. It offers a multi-perspective point of view in terms of the psychological computations and the neural mapping of both domains. More specifically, it focuses on the *transfer effects* from language to music and vice versa, including evidence from cases of aphasia and amusia, as well as on studies from tonal languages which suggest that their native speakers may display enhanced music capabilities. Moreover, neuroimaging studies further highlight the overlap or (and) the division of the neural pitch mechanism(s) between language and music. Thus, the behavioral and neuroscientific findings are linked to hypotheses that argue either in favor of a domain-specific, general or a music-relevant approach regarding pitch processing.

2.1 Behavioral and Neuroscientific evidence arguing in favor of a domain-specific hypothesis for pitch

If there is an analogous pitch mechanism for language, it would be intonation. Following such theoretical claims, Frances et al. (1973) investigated whether people diagnosed with aphasia and severe comprehension deficits are able to discriminate music tonality among short music sequence pairs. After exposure to the first piece, aphasics had to indicate whether the second piece of music is tonal or non-tonal. The results showed that aphasics were not able to discriminate the melodies in terms of their tonality. That deficit was called "melodic deafness" and pioneered a new field of research. According to Peretz (1993) though, the results of Frances et al. (1973) must be read with caution due to methodological issues. For instance, in that study they made the conclusion that the deficit of "melodic deafness" might lie behind an impaired pitch perception system that is music-specific, although only half of the controls showed above chance scores. Peretz et al. (1994) investigated two patients with bilateral lesions in the auditory cortex to further check whether their reported pitch deficits are specifically related to music. In a series of experiments, Peretz and colleagues use pre-recorded materials to assess recall and recognition of familiar melodies (rhythm, music memory), recognition of lyrics (language), discrimination and recognition of unfamiliar tunes (pitch direction changes), recognition of environmental sounds (non music or verbal sounds), musical instruments, prosody (intonation), voice recognition and discrimination, singing and related expressive behavior. The results of both cases showed impaired recognition of familiar tunes, pitch discrimination, perception of speech prosody and recognition of familiar voices. However, they preserved their rhythm discrimination abilities and the recognition of environmental sounds. In a further analysis, it was revealed that music deficits were proportionally greater for music, compared to speech, suggesting distinct neural pitch processing systems. During the '90s, those cases of accidental music impairments resulted from brain damage, led researchers to the division of acquired from congenital amusia, giving rise to a modular approach for pitch within the field of music.

2.1.1 Congenital amusia

Congenital amusia, alternatively called “tone deafness”, is characterized by a deficit in the production and perception of melody (specifically in pitch), that is not attributed to brain damage, hearing loss, cognitive impairment or lack of music exposure (Peretz et al., 2002). In contrast, acquired amusia refers to a state where after accidental brain damage, an individual might present deficits in various music aspects (e.g. pitch, rhythm, lyrics) (Marin & Perry, 1999). Prior research that investigates the cognitive/neural association of intonation with music pitch has focused on cases of congenital amusia due to the specificity of the deficit that is pertained to pitch, claiming that there might be transfer of deficits in non-music domains.

The first documented findings of congenital amusia comes from Peretz et al. (2002) who tested one case study (Monica) via discrimination tasks to check whether she is able to discriminate rhythm and pitch changes, local interval patterns, as well as recognition of familiar voices and environmental sounds. The results showed that Monica was able to discriminate rhythm relatively well, but her pitch performance was quite poor. She also displayed a deficit in the detection of wrong pitch changes, while her scores in the recognition of familiar voices and environmental sounds (e.g. barking dog) were significantly better. Thus, Peretz and colleagues made the conclusion that Monica presents deficits that might be specific to music pitch. They further tested this hypothesis by exposing her in a tone sequence task in which she had to detect pitch changes. In a similar linguistic task, they also tested whether the pitch deficit is apparent in speech, constructing pairs of sentences that consisted of rise or falling pitch on the last word. In that way, the sentence resulted as a question or a statement respectively. The results for the music task showed that she is able to detect pitch changes when the pitch is rising, but not when it is falling. Controversially, the results of Monica for the linguistic task were comparable with the performances of the control subjects, indicating that the pitch system is specifically impaired for music[3]. Linking those findings with prior aphasic neuropsychological studies which report that patients display language-specific deficits with intact music abilities, it is reasonable to assume that music is a modular system, as language, with subsystems such as pitch (Peretz & Coltheart, 2003 for a general review).

In the same line of reasoning, Peretz (2008) provides with further behavioral, neuroscientific and genetic evidence regarding the modularity of music pitch. At a behavioral level, Peretz suggests that music requires high level of decoding due to the small pitch interval distance between the notes that are based on a tonality, making it a unique process, compared to similar linguistic cues such as intonation. At a neurological level**,** she claims that the deficit of congenital amusia is probably attributed to an abnormal neural connectivity in the right (or bilateral) temporo-frontal network**,** resulted from less white matter with no obvious neurological abnormality. That region may, therefore, be related with music processing specifically. At a genetic level**,** she further states that since in language there is abnormal grey matter in another portion of the brain area, compared to music, and since language disorders have substantial differences from music deficits, it is expected that the genes will also be different for music. She supports that claim based on studies from identical twins which reveal that siblings have similar pitch decoding capacity, compared to non-identical twins, who display individual differences. In conclusion, Peretz proposes that congenital amusia is concerned with a core deficit of pitch processing in a

[3] This cannot be attributed to impaired working memory since the rising pitch detection was intact.

musical context[4]. Therefore, music might have a different neurological and genetic basis from language, characterizing pitch as a music-specific process.

Most recent evidence, along the same line of reasoning, highlights that the arcuate fasciculus (AF), a neural fiber tract that has been associated with speech development and links fronto-temporal brain areas such as, Broca's and Wernicke's, is also critical for music (Chen et al., 2018). 30 Mandarin amusics completed an identification lexical tone task (direction of the lexical tone) and a tone discrimination task (same-different), while investigating their neural connectivity. Contrary to the left AF that shows sensitivity in speech processing, Chen and colleagues reported that people with amusia display a malfunction of the white matter structures in the right anterior homologue AF, compared to the control groups, associating this area with music. In contrast, the anterior AF of the left hemisphere showed a strong correlation with speech processing. It, therefore, seems that the left AF may be involved in linguistic pitch, while the right AF for music pitch respectively, suggesting distinct pitch processing systems between language and music.

Although prior research reports deficits on the detection and production of music pitch variations, most of the amusic subjects were tested in non-tonal languages. Those languages are more coarse-grained in terms of pitch processing, compared to music or tonal languages, making it easier for amusics to process information (Peretz, 2008). Thus, contrary to music, this might make more likely for amusics to detect intonation contrasts in speech due to the low level processing demands. Modular neuroscientific evidence for pitch can also be explained under the view that other linguistic factors such as meaning that accompany intonation, might lie behind the reported neural dissociation of linguistic and music pitch. Therefore, it is not certain whether pure intonation processing is linked with language associated brain areas such as the left arcuate fasciculus. The next section offers a different point of view, supporting the idea that pitch might share an underlying process with intonation, providing evidence mainly from tonal languages such as, Mandarin Chinese.

2.2 Behavioral and Neuroscientific evidence arguing in favor of a domain-general hypothesis for pitch

A significant amount of behavioral studies in typical population reveals that there are *transfer effects* from language to music and vice versa, arguing in favor of a shared mechanism responsible for pitch processing. They suggest that speakers of tonal languages display enhanced music tone perception and that trained musicians show better linguistic tone perception respectively (Wong et al., 2007; Bidelman et al., 2011). In the same line of reasoning, it has also been reported that music abilities may lead to general phonological advantage in second language learning (Slevc & Miyake, 2006; Knickerbocker, 2007).

Further evidence related to transfer effects from language to music may come from Pfordresher & Brown (2009) who tested whether people who speak a tonal language also display enhanced music pitch production and perception capabilities. In that study, they found that native speakers of tonal languages, such as Mandarin, Cantonese and Vietnamese have better performances under imitation and discrimination of interval music pitch demands, compared to the native speakers of intonation languages (e.g. English). The main outcome of the paper is that tonal

[4]Most research on amusia uses the same tool to assess an amusic individual. The tool involves different assessment components that are considered crucial for Western tonal music such as, pitch, musical scales, rhythm, meter etc. *Montreal Battery of Amusia Evaluation* (Peretz, Champod, & Hyde, 2003).

languages in which pitch carries lexical information, may lead to enhanced music pitch capabilities, suggesting pitch transfer effects from language to music. Neuroscientific evidence encourages that claim, suggesting that the brainstem which is involved for frequency-related stimuli is significantly sensitive to speech and music (Krishnan et al., 2012). Similarly, Musacchia et al. (2007) reported that the frequency-related brainstem responses are enhanced in people with music abilities. It, therefore, seems that linguistic pitch capacities might lead to enhanced pitch performance in music.

From another perspective, neuropsychological evidence in atypical population reveals that music pitch deficits might be extended to linguistic intonation processing. Patel et al. (1998) investigated this assumption by explaining that prior research has used inappropriate linguistic tasks to test intonation in amusics, as well as that there were no previous cross-domain studies. Thus, Patel and colleagues tested the prosodic and music discrimination capabilities in two people with congenital amusia. The prosodic tasks consisted of sentence pairs that differed in intonation and rhythm. The musical discrimination tasks also had music pairs, making the tasks analogous in both domains. One amusic showed similar discrimination performance in both domains, while the other one scored poorly across domains. Thus, researchers concluded that there might be indications for an overlap in the processes related to prosody and music perception that requires further investigation. In a consequent behavioral review, Patel et al. (2008) state that prior behavioral findings argue that people with congenital amusia are able to discriminate speech intonation changes that lead to a statement or a question (Ayotte et al., 2002; Peretz et al., 2002). However, according to Patel and colleagues, among French-Canadian and British amusic participants of two independent studies, it was found that about 30% percent of those participants are not able to detect the direction of the pitch changes that make the sentences either a statement or a question (Lochy et al., 2004; Patel et al., 2005). This led researchers to the conclusion that amusics might be able to detect pitch changes in intonation, but some individuals display problems detecting the direction of the pitch (rising, fall). In another study, Liu et al. (2010) conducted 5 intonation perception and pitch threshold tasks to test whether 16 British amusics would be able to detect pitch changes in speech, as well as the direction of those pitch variations. According to Liu and colleagues, prior research has used higher thresholds of intonation pitch (5-12 semitones[5]) (Ayotte et al., 2002; Peretz & Coltheart, 2003; Peretz, 2006, 2008; Patel et al., 2008), while it has been suggested that amusic's pitch perception capacity threshold is approximately 2 semitones (Foxton et al., 2004). Therefore, this could explain prior reported performances of amusics that showed almost intact intonation processing capabilities, as well as the hypothesis that the pitch deficit in amusics might be music-specific. To further test this alternative view, Liu et al. asked from the participants to identify and imitate the variation of pitch (statement – question) in order to check the perception and production of pitch and if they are able to detect smaller pitch contrasts and their direction. The results showed that amusics are not able to discriminate small pitch contrasts in the final sentence position, making it impossible to perceive whether the utterance is a statement or question. When they were asked to imitate the intonation contrasts, compared to the control groups, they were still unable to do it so. It led researchers to the conclusion that congenital amusia might display a general pitch deficit that pertains to the inability to locate the directionality of pitch. Taking those results into account, it would be reasonable to

[5] In western music, a semitone is the smallest interval unit within two notes.

assume that if the exposed pitch requires low processing demands, the performances of amusics are expected to be similar with the controls. In contrast, if the demands of pitch processing are higher, then it is expected that they will also face greater difficulties, even in domains beyond music.

In support of this hypothesis, neuroscientific evidence claims that music capabilities may lead to transfer effects in language. For instance, the review of Bessom et al. (2007), states that musical expertise enhances musical processing and leads to change of specific brain structures. Some of those brain areas (e.g. inferior frontal gyrus, cerebellum, primary motor cortex) have also been associated with language. Following this view, Bessom and colleagues investigated whether music expertise has positive transfer effects in language, using discrimination tasks with various pitch contrasts while measuring brain responses. Regarding the linguistic tasks, they used sentences with subtle and weak pitch changes at the end of the sentence. Then, they divided those who had music expertise, expecting that they would be able to detect both the subtle and weak pitch changes in the musical tones that accompanied the sentences, as well as the linguistic pitch that accompanied the words. In contrast, those with no music expertise were not expected to detect the weak pitch changes both in music and language tasks. The results showed that adults and children musicians had lower error rates for the weak pitch changes in the tasks, compared to the non-musicians. This effect also appeared in the elicitation of the ERP components which was different in musicians, compared to the non-musicians, suggesting greater sensitivity in the general pitch processing for the musical experts. In another tone perception task, Bessom et al. also found that musicians were better able to discriminate the pitch changes in mandarin tones, compared to non-musicians, even though none of the participants understood the language, supporting that musical expertise might enhance second language learning. Furthermore, they also referred to a study in which dyslectic children after 6 month of musical training were able to enhance their performances in pitch discrimination in speech. Specifically, before music training, the pitch discrimination rates of dyslectics were significantly lower, compared to the non dyslectic children. The ERP data also showed no pitch-response for the dyslectics. However, after they received musical training, the results revealed that their rates were similar with the non-dyslectic children, as well as the activation of the ERP components. Thus, it seems that musical training enhances pitch abilities of dyslectics in speech. Moreover, Wong et al. (2007) investigated whether musicians are able to detect linguistic pitch changes more accurately, compared to non-musicians, through the exposure of three different tones of the Mandarin word “ma”. The results showed that musicians displayed enhanced linguistic pitch abilities, compared to non-musicians, suggesting a common sub-cortical neural pitch network among language and music, as further shown through the measurement of the frequency following response (FFR).

It is, therefore, clear that pitch and intonation might share an underlying process and that there are transfer effects from language to music and vice versa. This has become evident through tonal language speakers who display enhanced pitch perception capabilities, as well as through neuroscientific evidence which supports that language associated areas might also be involved for music. Moreover, cases of amusia reveal that music-specific deficits might be extended in speech, suggesting an impaired domain-general pitch system, as shown under various pitch discrimination demands. In the same line of reasoning, Confavreux et al. (1992) reports a patient with amusia and aprosody with intact cognitive functions and spared linguistic aspects. Additionally, Bautista & Ciampetti (2003) claimed that damage in the right brain region in an individual (43 years old woman) caused deficits both in the affective prosody (intonation) and expressive amusia (pitch), stating that after the stroke her speech became monotonic, while she also experienced difficulties when singing (she was a member of a church choir). In sum, studies presented on this section in people with congenital amusia come from non-tonal languages (e.g. English) that make use of intonation. However, tonal languages differ in some phonological aspects because pitch carries lexical information. The next section focuses on tonal languages (e.g. Mandarin Chinese) to test whether amusics display an even greater deficit rather than in non-tonal languages.

2.2.1 Congenital Amusia and tonal languages

The strongest findings which suggest that pitch might be a domain-general process between language and music may come from more recent studies related to congenital amusia and tonal languages. In those studies there is an attempt to test the hypothesis whether people diagnosed with congenital amusia would display impaired perception of lexical tone processing in tonal languages. Following this assumption, there is also an effort to detect whether the deficit is attributed to lower threshold capacities of amusics, leading to detection inabilities of pitch changes and (or) misperception of pitch direction.

According to Nguyven et al. (2009), tonal languages such as, Mandarin Chinese, make use of smaller pitch contrasts, compared to non-tonal languages (e.g. English), which differentiate the meaning of the words. For instance, the syllable “ma” means “mother” in the regular lexical tone, while a dipping tone gives the meaning of a “horse”. In their study Nguyven and colleagues investigated 20 French native speakers diagnosed with congenital amusia that had no experience in tonal languages to check whether the pitch deficit is extended into the discrimination of lexical tones. A native speaker of Mandarin pronounced pairs of words with four different tones: regular tone, mid-rising, dipping, and high-falling tone. After familiarization with the task, amusics had to indicate whether they are able to discriminate those variations of the tones. The results showed that 15% of the amusics (3/20) were not able to discriminate the lexical tones. It, therefore, seems that this small effect might be attributed to a general reduced discrimination capacity of the interval pitch sizes of the lexical tones. In a similar study, Jiang et al. (2010) further investigated the pitch deficit of amusics in tonal languages, by conducting a music and intonation discrimination task in 11 amusics whose native language was Mandarin. In the music task, participants were exposed in pairs of melodic contours and they had to indicate a potential violation of a pitch change in the melody. In the intonation task, subjects had to indicate whether pairs of two syllables (verb-object) express intonation contrast, leading to a statement or a question. Half of the pairs were identical, while the other half differed in lexical tone. The results revealed that amusics who displayed deficits in the music discrimination task also showed significant lower performance in the perception of intonation in Mandarin, although they had not reported any speech inability. Liu et al. (2012) further tested the hypothesis that pitch deficits in congenital amusia might be extended in tonal languages (Chinese). Thus, they designed tone perception tasks using smaller tonal contrasts, ranging from 1.5 to 4 semitones on average. 13 amusics showed impaired word discrimination skills, suggesting that pitch processing is a domain-general process that might not only linked with music, but also with tonal languages.

In the same line of reasoning, neuroimaging evidence seems to support prior behavior findings that indicate transfer of pitch deficit of amusics in lexical tone and intonation discrimination tasks. Jiang et al. (2012) conducted a combination of a behavior and brain imaging ERP study to test whether Mandarin amusics display similar perception judgments (appropriate vs inappropriate tones), as well as brain sensitivity with the controls. The results showed that controls present larger P600 component (violation) for the inappropriate prosodic stimuli and smaller N100 elicitation (attention of the relevant stimuli) for the appropriate stimuli, compared to amusics. In contrast, people with congenital amusia displayed insignificant differences among conditions, indicating that they were unable to detect the prosodic differences both at a behavioral and a neurological level. In another study, Lu et al. (2015) provide with further brain imaging evidence, conducting an EEG study while 22 Chinese amusics had to match emotional words of "joy" and "ugly" with intonation contrasts that lead either to a statement or a question. The results showed that their performance was significantly lower in the intonation-matching task, compared to the controls. EEG analysis also revealed that N2 response was reduced in amusics. However, further analysis showed that early sensory auditory processing was comparable with that one of the controls, indicating that amusics might be unable to process information at later stages where pitch information requires a higher level of processing.

It, therefore, seems that amusic's pitch deficit is extended in speech, both in tonal (lexical tones) and non-tonal languages (intonation), suggesting that amusics may display a generally impaired perception of pitch. Although this claim challenges modular approaches regarding pitch, it seems more likely that amusics may make use of other linguistic cues (semantics) to compensate for their pitch deficit, or that their pitch capabilities are intact in low processing levels, explaining their ability to complete prior linguistic pitch tasks, as well as the overlap found in brain imaging studies. The next section turns on that mid-point of view which seems to be the dominant approach of the current research on pitch between language and music.

2.3 Alternative Behavioral and Neuroscientific evidence arguing in favor of a music-relevant hypothesis for pitch

So far, there is a significant amount of evidence which argues either in favor of a domain-specific or a domain-general pitch mechanism among language and music. While findings are contradictory, it seems that pitch is a mechanism that has mainly been associated with music. This view has been steadily gaining ground through the investigation of cases with congenital amusia, a disorder that is pertained to a pitch deficit, especially apparent in music competence. Moreover, there is strong behavioral evidence which reveals transfer effects from language to music and vice versa, through exposure to tonal languages or via music training respectively. In the same line of reasoning, it has also been reported that people with congenital amusia display lexical tone and intonation deficits, as shown in behavioral and brain imaging tasks. However, this association or dissociation of pitch among language and music may be explained through the conception of an alternative view which states that pitch might be a music-relevant mechanism. This is attributed to the higher processing demands of music which is based on discrete pitch intervals, contrary to linguistic intonation which is more continuous with respect to the contrasts required for speech processing (Zattore & Baum 2012). Thus, language and music may share an underlying sound mechanism during the early auditory stages of pitch processing that lead to distinct representational systems (i.e. language, music). Therefore, disorders such as, amusia and aphasia might characterized from deficits at representational level, explaining the overlap and the dissociation that has been mentioned in neuropsychological and neuro-imaging studies in prior sections (Patel, 2010). Lastly, music pitch might share common neural networks with language, despite the prominent role of pitch in music. This section encourages that view, providing evidence mainly from neuropsychology.

In line with this hypothesis, Ayotte et al. (2002) claimed that pitch in music demands more fine-grained processing, contrary to intonation which has larger and more distinguishable pitch contrasts, supporting the idea that pitch might be a music-relevant mechanism. Once pitch processing demands in speech are high though, it is expected that amusics would display transfer of pitch deficits in intonation processing too. Ayotte and colleagues tested this hypothesis by conducting pitch detection tasks (same-different) in music and intonation. In the music task, participants had to indicate whether pitch is same or different among pairs of melodic contours. Similarly in language, they had to detect the direction of pitch (rising or falling) that displays a statement or a question and the point that pitch changed. In another task, they also had to discriminate the intonation changes without any linguistic information. This was done by removing all the linguistic information from the task via a computer program, leaving the intonational aspect intact. It was found that only in the latter task amusics showed significant poor performance, analogous to the music tasks. According to Ayotte and colleagues, amusics might have an impaired domain-general mechanism for language and music that is perceived as music-relevant due to the high pitch processing demands that music requires. It, therefore, seems that the deficit can be detected in speech when amusics have no other cues to compensate for the pitch deficit such as using contextual meaning. In a similar study, Patel et al. (2005) investigated the perception of intonation in 7 amusics using the same method, as fore-mentioned studies, to test whether they are able to detect pitch changes in identical sentence pairs with different intonation. Amusics were found to be unable to detect the changes of the last word that made the sentence a statement or a question. According to Patel and colleagues the problem might not lie in the lower psychophysical thresholds of amusics, as it has been suggested (Peretz & Hyde, 2003), but to a deficit that is extended beyond the detection of pitch changes and is related to the direction of the change. Thus, this view might explain why prior research has found that amusics perform well in intonation tasks that have simpler pitch contrasts, compared to music tasks that are more discrete. In another similar study, Hutchins et al. (2010) tested the perception of amusics in an intonation and a music task, using intonation contrasts in identical sentences, indicating a statement or a question (e.g. statement: “He speaks French.”, with falling pitch at the end of the sentence, whereas in question: “He speaks French?”, with rising pitch at the end of the sentence) and rising-fall for music respectively. This task was expected to reveal that if there is any effect in pitch discrimination abilities, it will be simply due to pitch manipulations that do not rely on other cues, since meaning can only be affected by the direction of pitch. Overall, the results showed that amusics performed poorly in categorizing the direction of pitch both in music and speech, indicating that there is a general deficit in pitch that becomes apparent under controlled linguistic factors.

In the same line of reasoning, Zattore et al. (2002) provided neuroscientific evidence suggesting that core cortical brain areas in the left hemisphere might be involved in low processing level of pitch information, making it specialized for language. On the other hand, music pitch might be processed in a complementary neuronal network in the right hemisphere, shaping the modularity of music perception, supporting the idea that pitch in language and music may overlap in low processing levels. In turn, pitch might have evolved in right sub-cortical areas of music due to the higher processing demands, in an analogous way as linguistic mechanisms dominate in the left hemisphere. These findings are linked with consequent neuro-imaging data which show that the right auditory-frontal cortical circuitry plays a crucial role in fine-grained pitch processing (Hyde et al., 2007; 2011; Loui et al., 2009). Thus, there are indications that pitch deficits might be at the level of more accurate pitch processing in both domains (Hyde & Peretz, 2004) which seems to be more critical for music than for speech. Further neuro-imaging studies that tested pitch perception found that pitch lexical distinctions in tonal languages reveal a left hemisphere activation bias, compared to the pure pitch processing that typically activates the right hemisphere (Zatorre & Gandour, 2008). However, this interpretation does not imply that there are distinct pitch systems between language and music. The left hemisphere bias could be the result of an interface among prosodic, semantic and syntactic information (Patel, 2011). According to Patel, pitch could be a shared process in early auditory cortical processing that may be distinguished depending on a linguistic or a musical context. Music perception may be affected more from pitch deficits due to the fine-grained demands of music, compared to speech. Moreover, the perceptual threshold of amusics might display lower capacities, making them unable to reach the required level in order to process pitch variations, especially in music.

Summarizing, past studies have shaped three different views regarding pitch processing that seems contradictory at first glance. First, the traditional approach supports that pitch is a music-specific mechanism, therefore, unique to music. This may be evident through neuropsychological and neuroimaging findings which claim that amusia displays distinct deficits from aphasia and that amusic individuals show intact general cognitive abilities, language skills and more specifically, intonation processing (e.g. Peretz, 1993; Peretz et al., 1994; 2002, Marin & Perry, 1999). In turn, following those claims, the post-traditional view (dominant during 2000-2010) suggests that music pitch shares common neural resources with intonation, as shown through neuroscientific and behavioral evidence which reveal neural overlap of music pitch processing with language associated areas (e.g. Krishnan et al., 2005), as well as transfer of music pitch deficits in speech (e.g. Bautista & Ciampetti, 2003; Patel et al., 2008; Nguyven et al., 2009; Liu et al., 2010; Jiang et al., 2010; 2012). Moreover, there are also findings which report transfer effects from language to music and vice versa (e.g. Wong et al., 2007; Bessom et al., 2007; Bidelman 2009; Pfordresher & Brown 2009). The most dominant approach regarding the music-relativity hypothesis of pitch (e.g. Zattore et al., 2002; Ayotte et al., 2002), suggests that pitch is a more music-relevant mechanism due to the fine-grained processing demands of music which has discrete frequency contrasts, contrary to language in which intonation contrasts are more easily distinguishable due to the continuous frequency contrasts (e.g. Patel 2010; 2011; Zattore & Baum 2012). Adopting that view, it seems that past theories can be explained by the view that even amusics who display lower music pitch capabilities are able to process easy intonation contrasts, since their threshold may not be exceeded, leading to comparable performances with the controls (Patel et al., 2005). Thus, those tasks might not be indicative of the level of their pitch capacities, attributing impairments in music aspects that are more detectable. Hence, smaller pitch intonation contrasts that demand more processing revealed poor performances in amusics in intonation detection tasks (e.g. Patel et al., 2005). Alternatively, it might also be the case that amusics may use other linguistic cues to success in the tasks (Ayotte et al., 2002) challenging the hypothesis that speech is unimpaired in amusia. Moreover, the music-relevant hypothesis could also explain the neural overlap of linguistic and music pitch found in neuro-imaging studies, since it could be a result of a shared mechanism at a lower processing level. Moreover, it has also been reported that the deficit of amusics is attributed to a general impaired pitch mechanism that reveals relative good performance in the detection of pitch changes up to a certain extent, but not to the direction of those changes (rising, fall), as shown in pitch detection tasks in both domains. Those explanations could argue in favor of the hypothesis that pitch might be a shared process between language and music in low processing levels and that there is a common pitch deficit in music and speech in amusics that is pertained to the direction of pitch. This may be evident if the tasks demand complex pitch decoding that other cues cannot compensate.

The main outcome of the present literature review is that in computational terms linguistic pitch is a relatively effortless process for speech perception and compensable in cases of amusia, compared to music pitch that demands a more-fine grained process and is easily detectable in amusia. Moreover, if pitch and intonation indeed share an underlying mechanism at a low processing level and it is music that imposes higher-order demands, then it is reasonable to assume that pitch is a single mechanism that may lead to distinct representational systems in linguistic and musical contexts. Thus, based on those assumptions, it is expected that in an ambiguous context where intonation would normally resolve ambiguity, an even more fine-grained process that is resulted from the same pitch mechanism might also be able to compensate for intonation. Adopting that view, it is expected that music pitch could function as a cue for disambiguation, contributing to language comprehension. The present experiment is in Greek which is a non-tonal language and speech contrasts are continuous, making them easy for processing. In contrast, the western music pitch scales that are used in the task, instead of intonation, demand a more fine-grained processing. Therefore, the activation of a higher-order processing of pitch, resulted from a shared pitch mechanism, is expected to affect the processing of the ambiguous sentences which should become evident through the judgments and reading times of the participants in a self-paced reading-listening task.

3. Method

The present experiment is a self-paced reading non-cumulative task combined with music[6]. Specifically, word segments are accompanied with the simultaneous onset of musical notes. Thus, after the processing of each word and the hearing of the musical notes, it ends up to a whole sentence and a melody respectively. After the completion of the sentence, it follows a comprehension question to ensure that participants attend the task and they are not simply guessing. In that way, the task measures reading times (in ms) across segments and evaluates comprehension judgments in order to conduct behavioral results for language comprehension of individuals through their response times and rates.

The experiment is in Greek and it consists of six conditions to test the hypothesis whether high music pitch, compared to neutral and low music pitch, can substitute linguistic intonation, resolving garden-path effect and contributing to language comprehension. Following the example (*"Yesterday/Χθες |while/ενώ|(they) were recording/ηχογραφούσαν| the violins-pl-nom/acc/τα βιολιά| were sounding/ακούγονταν| out of tune/παράφωνα.|"*), if there is intonation with high emphatic linguistic tone on the third word segment, the garden-path effect is resolved on the 5th word segment (critical region). This has also been shown in prior Greek behavioral evidence which showed shorter reading times in the critical region in sentences with similar structure when high linguistic tone is used on the first VP, compared to a condition that there are not prosodic cues (Papangeli & Marinis, 2010). Therefore, if there is a common underlying pitch process between language and music, it is expected that non-linguistic cues, such as music pitch might lead to similar results. To test this hypothesis, the present experiment used the following conditions:

1. Ambiguity + high music pitch (523 Hz)
2. Ambiguity + neutral music pitch (391 Hz)
3. Ambiguity + low music pitch (293 Hz)
4. Non-Ambiguous + high music pitch (control)
5. Non-Ambiguous + neutral music pitch (control)
6. Non-Ambiguous + low music pitch (control)

The experimental conditions consist of ambiguous sentences that cause garden-path effect with the simultaneous onset of music. Specifically, instead of intonation on the first VP, depending on the condition, it is used high, neutral and low music pitch. If there is a common mechanism of pitch between language and music, then it is expected that high pitch can substitute rising intonation in terms of acoustical processing, disambiguating a sentence, therefore, leading to shorter reading times, compared to the neutral and low condition that are not expected to eliminate garden-path effect. Regarding the control conditions, it is expected that they should show that reading times in high music pitch exposure in the non-ambiguous condition are similar with the correspondent experimental condition, while neutral and low pitch control conditions should not reveal such an effect. Therefore, it would indicate that high pitch resolves garden-path effect and the sentence is processed as a non-ambiguous sentence. Moreover, it is expected that the non-ambiguous neutral and low (control) conditions will display shorter reading times, compared to the corresponded experimental conditions in which neutral and low music pitch are not expected to

[6] The task designed in a stationary-window. As a result, reading times are not affected by eye-movements.

resolve garden-path effect, leading to longer reading times. More specifically, low music pitch exposure might delay processing even more, compared to neutral pitch in an ambiguous sentence. This is based on the idea that deviant pitch might function as a distraction cue. In that way, it may further highlight that a potential facilitation effect of the high pitch is not simply due to an accidental manipulation in pitch.

Participants

The present experiment has been approved from the University of Crete. 72 Greek participants were recruited from Heraklion of Crete through a post on social media, acquaintances that were willing to participate and students from the foreign language center *Paneuropia* where the experiment took place. 22 subjects were males and 50 were females. Their age ranged from 20 – 31 years old (mean age: 25,47). All the participants that were included in the analysis were undergraduate, graduate and postgraduate students and they were familiar with reading. None reported any hearing/visual loss, reading difficulties and language or other disorders. 3 subjects were diagnosed with dyslexia and they were substituted with new participants. 8/72 were left-handed, however, the computer mouse was adjusted accordingly and it didn't affect the process of the task. 1/6 of the total number of the participants (12/72) had music expertise[7], making it possible to form a subgroup for further analysis. There was no financial compensation and participants were informed in advance. All of them were willing to participate and they were naive regarding the purposes of the experiment.

The factors of age, along with the educational and music background account for the control of the processing capabilities of the subjects and their cognitive capacities such as, memory. Although it has been reported that non-musicians detect pitch contrasts in music and they process it automatically, even if they are instructed to attend language and ignore music in simultaneous onset contexts (Koelsch et al., 2005), a separate analysis took place for the musicians to further test the debatable hypothesis whether music training leads to enhanced linguistic perception[8]. According to the experimental hypothesis of the present thesis, it is not expected that musicians process differently high music pitch in place of intonation, compared to non-musicians. If pitch shares an underlying process between language and music, it is expected to be an innate one, regardless of music experience. If musicians display enhanced perception on that process though, it is a topic beyond the purpose of the present manuscript.

Materials

The experiment took place in a class that it was not soundproof. However, it was very quiet and none reported any external noise or distraction. For the experiment it was used a Samsung laptop with Zep 1.17.1 software (Veenker, 2019), two USB speakers and one computer mouse. In prior, similar self-paced experiments (Slevc et al., 2009; Fedorenko et al., 2009), it has been used headphones instead of speakers. However, this was avoided for two reasons. First, due to Covid-19 it was not feasible to use different headphones for each participant. Despite that, during piloting that preceded real testing, it was observed that USB speakers made the task more naturalistic and

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[7] They reported more than 3 years of systematic music training and were actively musicians.

[8] It has been suggested that in most cultures pitch changes of one octave can be detected even by novice listeners (Dowling & Harwood (1986) in Patel et al., 2010)

both stimuli types had greater synchronization onset. The volume that was used was approximately 100 db across subjects. None reported that loudness distracted them when they were asked.

There were 2 practice items across participants that follow the patterns and length of the real sentences (e.g. "Yesterday while (she/he) was playing the violin(,) Anna was writing") and 27 sentences in the test phase (see Appendix 1 linguistic stimuli). 3 of those were fillers[9] that also follow the same structure and they functioned as distraction during the task. For each condition there were 4 items that overall result in 24 experimental items (4 items per condition). 12/24 were items that caused garden-path effect. This psycholinguistic phenomenon occurs in Greek when the NP *the violins/τα βιολιά* (see figure 1*),* due to the morphological flexibility in case, can be attached either in the preceding or in the following VP. If it is attached in the first VP (*were recording/ηχογραφούσαν)*, it has the role of object. In contrast, if it is attached in the second VP *(were sounding/ακούγονταν),* then it is interpreted directly as its subject. In terms of processing, readers tend to confuse once they reach the second VP, due to the need of re-interpretation. Once this happens, they eventually interpret *the violins/τα βιολιά* as the subject of the second VP and the sentence is disambiguated. The rest 12/24 items correspond to the control conditions and they are morphologically manipulated in such a way that the constituent *the violins/ τα βιολιά* does not agree in number with the verb of the second VP. Thus, there is no garden-path effect (e.g "Yesterday while (she/he) was recording the violins (she/he) was hearing mistunes"). For each item, a comprehension question was following (e.g "Were the violins sounding out of tune?/ Τα βιολιά ακούγονταν εκτός τόνου;"). In general, all the experimental linguistic stimuli were created in the same structural pattern for the purposes of the present experiment. A Similar structure of sentences that cause garden-path effect has also used in prior Greek linguistic experiments (Papadopoulou & Tsimpli, 2005; Papangeli & Marinis, 2010).

Regarding the musical stimuli[10] that accompany the word segments, there is a C major note[11] that functions as a context and it has the largest duration among the musical notes (1.08 seconds). That note is always attached into the word segment *Yesterday/Χθες* that is present across items. The note G4 is also present across stimuli and it accompanies the word segment *while/ενώ*. The reason that those segments were the same across items is just to ensure that high pitch will not be displayed too early in the sentence. The duration of *while/ενώ* and the rest notes was equal (0.641 ms) across music stimuli. Thus, if there are selective differences across segments, it cannot be attributed to the duration of music. At the same time, 0.641 ms functioned as a baseline for those who really attended the task. Shorter than 0.641 ms in reading times, might be an indication that some individuals have processed the segments too fast. The third segment was the emphatic-region where there is a music pitch variation, depending on the condition (high pitch C5, neutral pitch G4, lower pitch D4). The musical notes that followed that region were G4, E4 and C4 for the rest

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[9] The reason that fillers were only 3, and not as much as the experimental items, is because the task would demand more time and participants would get tired. None of the participants reported that they understood the purposes of the experiment or that they were biased with the expected items during the task.

[10] Music stimuli were syncopated piano notes in wav.file format that were created for the purposes of the current experiment.

[11] The first note shapes the perceptual tonal center, creating pitch expectancies (Patel, 2010).

three segments respectively. In sum, this creates the following melody (C2, G4, **C5/G4/D4**, G4, E4, C4) (see figure 1 for pitch details). This sequence, despite the fact that it displays three variations in the third note, it does not violate any music structure expectancy (they are in key). In that way, any potential effect in the processing of the sentence is expected to be simply due to pitch manipulations and not due to music syntax.

There were also music fillers that were identical with the experimental music items and they follow the same melodic pattern. However, the onset of a musical note in the third variation-segment was randomized to distract participants from any association of specific notes with specific items. This made participants completely naive for the purposes of the music onset and none reported that understood the function of music after the completion of the task.

Thus, high music pitch exposure in the 3rd segment is expected to determine the word boundaries of the sentence, as intonation does so, resolving garden-path effect. This is expected to become evident through the comparison of reading times in the critical (5th segment) and post-critical region (last segment) (see figure 1), in accordance with the comprehension judgments that further make clear whether participants resolved the ambiguity. Moreover, neutral music exposure in a preceding segment (3rd segment), is not expected to function as a key of disambiguation, leading to longer reading times in the critical and post-critical region, compared to high music pitch condition. Additionally, low pitch exposure in the third segment will reveal whether any facilitation effect is a result of simple sound deviation in pitch. If it is high pitch that indeed affects language disambiguation, then it is expected that low pitch will have the opposite effect, functioning as a distraction of pitch perception, delaying reading. In the control conditions, the non-ambiguous version of the sentences that do not cause any garden-path effect shapes the baseline for reading times in the critical and post-critical regions. Therefore, it is expected that high music pitch exposure in an ambiguous sentence will result in similar reading times in the critical and post-critical regions with the non-ambiguous version of the sentences. In that way, it will be possible to see whether high pitch resolves temporal ambiguity, as intonation does, as it will be shown through the processing of the garden-pathed sentences.

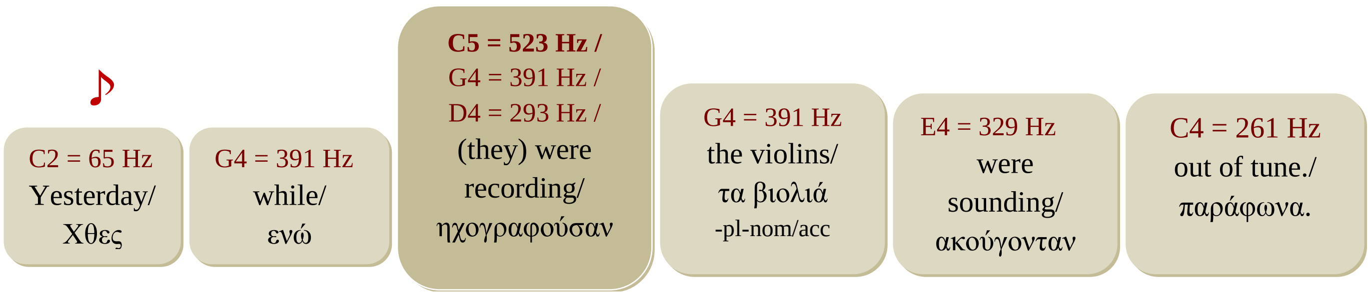

Figure 1: Schematic representation of the self-paced reading-listening task

The task involves six word segments in total that are accompanied with musical notes (one note per segment, see red letters). Every time participant press the button, the next segment appears in the middle of the screen simultaneously with music (listening), while the previous one disappears. This gives reader the opportunity to process segments with their own pace. However, they must pay attention to the word segments in order to retain them in memory, as this forms a sentence at the end. Once they proceed in the third segment (emphatic-region, see dark ochre segment), depending on the condition, there are three possible note variations. Thus, participants hear either a high pitch-523Hz note, a neutral pitch-391Hz note, or a low pitch-293Hz note. The rest segments display stable notes across items, regardless of condition, that can be linked with the preceding note variations, shaping a complete melody at the end. The 5th segment (second VP of the sentence) is the critical region where participants are expected to be garden-pathed. Thus, if high music pitch can substitute the use of intonation, resolving temporal ambiguity, reading times in the critical (or post-critical) region(s) are expected to be shorter, compared to a condition that music pitch cannot replace intonation (e.g. neutral music pitch).

Procedure

Before the beginning of the experiment, participants were informed that they are going to participate in a psycholinguistic experiment that pertains to language comprehension, as well as for their participation rights through a consent form. Once they were signing the form, and if there were no questions, they were sitting in front of the laptop. Before the beginning of the task, participants were kindly requested to attend to the screen and turning their mobiles into a flight mode. It was clarified that it was of great importance to complete the experiment without external distractions.

Participants were instructed to read the sentences carefully, even those who might appear several times, and that it will be a comprehension question after each sentence. They were not instructed to pay attention to music. However, they knew that that will be a musical note behind every segment. During the instructions, it was made clear that they are going to read segments word by word that will appear in the center of the screen, while there is simultaneous onset of a musical note (presented over speakers). Once they press *spacebar* they proceed to the next segment and so forth. After the completion of the sentence, there is always a comprehension question and subjects have to indicate whether the statement is correct or not (Yes, No). For their answers, they did not get feedback. Additionally, they were also informed that there will be a practice phase, just to ensure that they understand how the task works. At the end of the practice phase, there was a statement encouraging them to ask for any questions before the experimental phase. Once they were ready, they proceeded in the real task by pressing a button. The total duration of the experiment was approximately 10 minutes.

Design and analysis

The design of the task is a mix of a latin square and a within-subjects design. This means that there are items that participants did not see more than once, despite the fact that they went through all the conditions. On the other hand, there are 4 items (2 ambiguous sentences and 2 non ambiguous sentences) that all participants met across conditions that only differed in music. Thus, 12 experimental items represent the latin square design (2 different items x 6 conditions) and another 12 experimental items the within subject design respectively (2 identical items x 6 conditions). The reason of this manipulation is that it would be a risk for the reliability of reading times if participants were going though different items in every condition. It could also end up uncertain if any effect is a result of pure music manipulation or due to lexical differences. Therefore, to exclude this possible confound, two sentences were included across conditions to ensure that reading times differ only due to music pitch change. In this case though, the risk was that subjects might process identical sentences faster when they meet them more than once during the task and that their interpretations might be affected by prior reading. However, most participants reported that when they read an item more than once, they were still processing it as a novel instance.

The dependent variables of the study are reading times and comprehension judgments, while the independent variables are high, neutral and low pitch in two levels (ambiguous, non-ambiguous sentences). Items that had less than 50% correct comprehension rates were inspected to check whether there was an item-specific difficulty in processing or an inability to answer any of the questions. From the inspected items, it was only one item that excluded across conditions, but it didn’t affect the results significantly. Overall, through the rates of the comprehension judgments it seems that participants were attending the experiment and they answered accurately in most comprehension questions. Items that showed below 60% of correct answers were further analyzed to check whether there is any specific difficulty either in the process of the sentence or in the answer of the question. Through the analysis of those items it was found that processing times were close to the mean of the general reading times, indicating that subjects did not face any difficulties and that inaccurate answers might were due to comprehension difficulty of a specific question. For the statistical analysis, it was used *Python 3* (Rossum & Drake, 2009).

4. Results

Mean reading times are presented in milliseconds per condition, per sentence regions (see Table 1). Overall, correct answers of the comprehension questions were 84% correct, including those from filler items. The statistical analysis took place separately for each word segment. However, for the purposes of the present experiment, it focuses on the regions of interest, namely, critical and post-critical region (see Table 1). In general, two statistical models were used for the analysis of the data. For the comparison of the means of the three experimental conditions, it was used a one-way F-test (Anova)[12], while for the comparison of each experimental condition with the correspondent control condition, a two sample t-test.

Mean reading times for each condition per segment

	type	Emphatic region	Pre-critical region	Critical region	Post-critical region
0	AMBHIGHPITCH	1126.312500	1140.937500	1244.427083	1683.888889
1	AMBLOWPITCH	1120.829861	1161.736111	1158.805556	1716.875000
2	AMBNEUTRALPITCH	1099.486111	1151.666667	1330.684028	1692.572917
3	NONAMBHIGH	1095.281250	1250.465278	1097.798611	1710.590278
4	NONAMBLOW	1127.298611	1189.333333	1065.298611	1593.920139
5	NONAMBNEUTRAL	1069.697917	1138.500000	1073.965278	1492.520833

Table 1: This table shows the mean of reading times per segment per condition, as shown in the initial analysis of the overall data.

The initial analysis of the data (see Figure 2) showed that reading times in the critical region after high, neutral and low pitch do not significantly differ $F(2, 849) = 2.85$, p = .06. Similar results were found for the post-critical region as well F (2, 849) = 0.04, p = .96. As a result, it contradicts the experimental hypothesis, supporting that high music pitch, compared to neutral and low pitch, does not lead to enhanced linguistic processing, disambiguating a sentence as intonation would do so. However, it was noticed that in the post-critical region, reading times are similar between the ambiguous high pitch condition and the correspondent control condition $t(574) = -0.21$, p = .83, indicating that reading of the sentences was processed similarly in both cases. In contrast, low and neutral pitch ambiguous conditions lead to longer reading times, compared to the correspondent control conditions $t(574) = 1.11$, p = .26, although only neutral condition reached a significant difference $t(574) = 1.998$, p = .046. This could mean that although critical region is the moment where participants are supposed to be garden-pathed in the ambiguous conditions, they still proceed to the next segment (post-critical region), since they know that there is one more. Thus, it might be the post-critical region the real point where participant's processing is more reliable. Moreover, through the analysis of the comprehension judgments of the participants, it was noticed that there was an experimental item that had below 50% accuracy rates across participants. For this reason, a further analysis took place to ensure whether this item does not affect the results. The analysis of the experimental conditions revealed the same effects with the initial analysis, both in the critical $F(2, 825) = 2.79$, p = .06 and the post-critical region $F(2, 825) = 0.08$, p = .92. Again, high pitch condition had similar reading times with the correspondent high pitch non-

[12] Despite the fact that the comparison took place between three different groups of means, there was no need for post-hoc tests since there was not a statistically significant difference.

ambiguous condition and it didn't reach significance *t*(550)= -0.28, p = .78. Although neutral and low pitch conditions didn't also reach a significant difference in the post-critical region *t(550)* = 1.78, p = .08, *t*(550) = 1.62; p = .24, it seems that there is a similar pattern with the initial analysis.

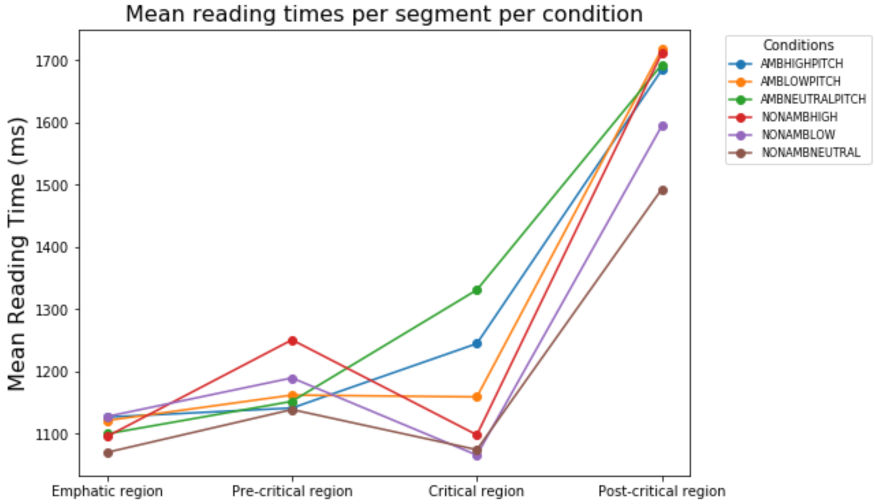

Figure 2: This figure shows reading times per segment per condition, as shown through the initial analysis of the data.

A second analysis (see Figure 3) took place for the group of musicians, to test the hypothesis whether they display (or not) enhanced linguistic processing due to possible transfer effects. In accordance with the initial hypothesis of the present experiment, they didn't display any different effect that reached significance either in the critical *F*(2, 141) = 0.51, p = .60, or in the post-critical region *F*(2, 141) = 0.78, p = .46, under high, neutral and low pitch exposure. It was only high pitch non-ambiguous condition that showed longer reading times in the post-critical region, compared to the correspondent experimental condition; however, the difference is not significant *t(94)* = -0.98, p = .33. Thus, the analysis of those subjects with professional musical experience leads to similar outcomes with the initial analysis of the data, supporting the hypothesis that musicians do not process pitch differently, compared to non-musicians, in linguistic ambiguous contexts.

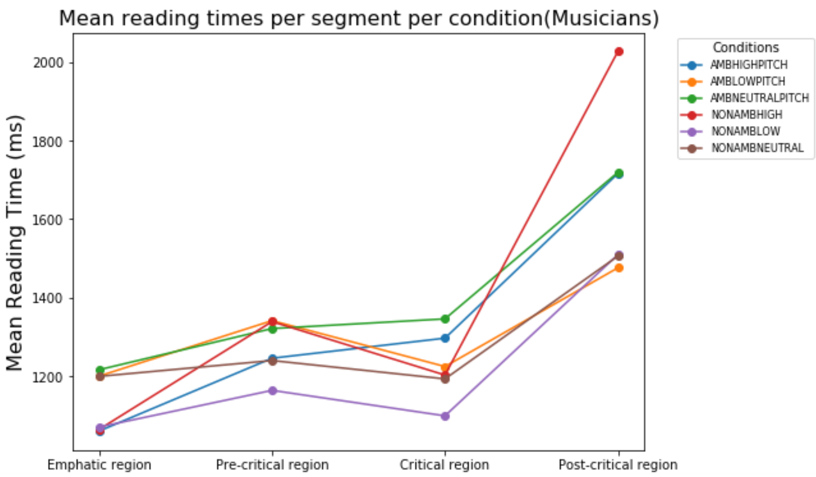

Figure 3: This figure illustrates mean reading times per segment per condition for the group of musicians (1/6 of the total number of the participants)

The present experiment has a mixed design (latin square and within-subjects design). Thus, a separate analysis was conducted to test whether within-subject's design data (which includes identical items across participants and conditions), lead to similar results with the initial analysis of the overall responses or if there is any different effect (see Figure 4).

Mean reading times for each condition per segment (within-subjects design)

	type	Emphatic region	Pre-critical region	Critical region	Post-critical region
0	AMBHIGHPITCH	1105.555556	1145.305556	1279.250000	1568.236111
1	AMBLOWPITCH	1064.638889	1135.326389	1086.791667	1720.027778
2	AMBNEUTRALPITCH	1098.993056	1163.090278	1322.201389	1663.562500
3	NONAMBHIGH	1091.500000	1233.180556	1038.722222	1774.243056
4	NONAMBLOW	1114.076389	1196.041667	996.479167	1484.993056
5	NONAMBNEUTRAL	1033.895833	1128.847222	1024.895833	1486.638889

Table 2: This table shows the mean reading times per segment per condition for the within-subjects design. Thus, those means reveal the performance of every perticipant when they met the same items in every condition where there was only difference in music pitch.

The analysis revealed that reading times (see Table 2) in the critical region do not significantly differ among experimental conditions $F(2, 429) = 2.39$, $p = .09$. However, it was only in low pitch exposure in the ambiguous sentences that led to similar reading times with the correspondent control condition $t(286) = 1.27$, $p = .21$. In contrast, high and neutral pitch in ambiguous sentences led to longer reading times (see Table 2), compared to the analogous control conditions and this difference reached significance $t(286)= 2.08$, $p = .03$, $t(286) = 3.17$, $p < .001$. This outcome rejects the experimental hypothesis, showing that high pitch does not function as a cue of disambiguation, leading to longer reading times. In contrast, it seems that low pitch facilitates reading in ambiguous sentences, supporting the idea that a random pitch manipulation might function as an emphasis that later on is proved important in order to determine the word boundaries and maybe lead to the disambiguation of a sentence.

Regarding the post-critical region, comparing high, neutral and low pitch exposure, it was not found a statistically significant difference $F(2, 429) = 0.39$, $p = .68$, indicating that high pitch does not facilitate reading in ambiguous sentences. Moreover, comparing the ambiguous with the non ambiguous (control) conditions, it seems that the ambiguous high pitch condition display shorter readings times, compared to the correspondent control condition, but they do not significantly differ $t(286) = -1.17$, $p = .24$. This effect was not found for low and neutral pitch respectively, although their differences in reading times were not statistically significant $t(286) = 1.45$; $p = .1$, $t(286) = 1.21$, $p = .23$.

In sum, the experimental conditions do not significantly differ with the control conditions. Despite the general increased rates of the non-ambiguous high pitch condition, it seems that the analogous high pitch experimental condition displays shorter reading times in the ambiguous condition. This might indicate that high pitch, compared to low and neutral pitch, leads to shorter reading times in the post-critical region where participants have really realize the interpretation of the sentence. However, since there is not a statistical significant effect for high pitch, it seems that the experimental hypothesis is rejected.

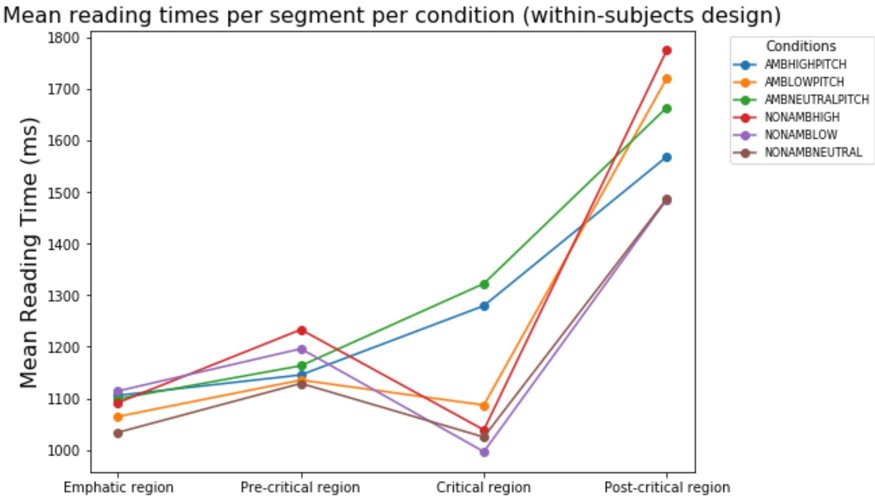

Figure 4: This figure illustrates mean reading times per segment per condition for the within-subjects design.

Another analysis was made to test whether participant's accuracy rates lead to variant results. For this reason the analysis was done only to those subjects with excellent performances (above 80% accuracy and no more than one mistake per condition). The results showed no significance in the comparison of the experimental conditions neither in the critical (p = .51) nor in the post-critical region (p = .48). Thus, the performances of the subjects who answered more accurately do not display different outcomes, compared to the overall performances of the participants.

5. Discussion

In general, the initial analysis showed that high music pitch cannot substitute the use of intonation, contributing to language comprehension. This was evident both in the critical and in the post-critical region, as shown through the comparison of reading times across conditions. This pattern was also found in separate analyses that took place and they tested people with musical experience, exclusion of inaccurate processing of specific items during the task and further analyses based on the comprehension accuracies of the participants. In all cases, the results are similar, arguing in favor of the null hypothesis. However, it seems that while comparing identical items across conditions (within-subjects design), the results show a greater effect in favor of the experimental hypothesis, not statistically significant though. More specifically, high pitch leads to shorter reading times in the post-critical region in the ambiguous sentences (*1568 ms*), compared to low (*1720 ms*) and neutral pitch (*1663 ms*), while they are also shorter from the correspondent high pitch non-ambiguous sentences (*1774 ms*) that were not expected to cause longer response times. An analogous effect was not found for low and neutral pitch conditions respectively. This might indicate that high pitch can disambiguate a sentence, since it is processed faster than the non-ambiguous version of the same sentences. That difference cannot be attributed to dissimilar processing times due to lexical differences, since the items were identical across conditions. Moreover, if we keep the explanation that the post-critical region is the real point where participants realize the interpretation of the sentence and that any potential effect of pitch should affect that region, then there are indications that high pitch might lead to the disambiguation of an ambiguous sentence, as intonation does so, determining the word boundaries of the sentence. Although the experimental hypothesis of the present thesis cannot be confirmed, future research could potentially shed more light on this hypothesis.

A possible explanation of the rejection of the experimental hypothesis may be that even if the pitch mechanism shares common processing resources between language and music, it is unclear whether music pitch and linguistic pitch are processed in a same time manner. Therefore, it cannot affect the understanding of a sentence during simultaneous processing. If the null hypothesis is accepted, future research is needed to take into account this factor. This scenario might explain prior findings which support that pitch might be a music-relevant mechanism due to the fine-grained processing demands of music, contrary to intonation that has not discrete pitch contrasts and it is not based on a perceptual tonal center, making it a less complex process (Patel, 2010). Thus, even if pitch shares common resources between language and music, the time that needs for music pitch to be processed is longer, making linguistic disambiguation impossible. However, this does not mean that pitch is a unique mechanism for music. Despite the recent contradictory evidence which claims that there is not clear neuroscientific evidence in favor of a domain-general mechanism responsible for pitch among language and music (Chen et al., 2018), future studies should focus on the distinct levels of processing information (developmental vs representational), while controlling for the variability and complexity of analogous stimuli such as, linguistic and musical pitch.

In terms of the underlying computational processes, following prior hypotheses (Patel, 2003) that argue in favor of the experimental hypothesis, it would be reasonable to assume that language and music share a common processing mechanism during the integration of pitch information. In this way, if there is a common underlying process in the auditory channel, at least during the early stages of decoding acoustical information, then it could be possible that high pitch might substitute the signaling of intonation, leading to a similar cognitive outcome, specifically to the affect of language understanding and disambiguation. In line with this hypothesis, the *Shared Sound Category Learning Mechanism Hypothesis* (*SSCLMH*) states that there must be a distinction between the shared developmental processes among domains such as, language and music, from the outcomes of those processes that might lead to domain-specific conceptualizations (Patel, 2010). Similarly, prior findings from clinical cross-domain research support that if pitch mechanism indeed shares an underlying process between language and music, a potential treatment could be through cross-domain approaches. More specifically, they claim that the combination of linguistic pitch and rhythm leads to increased informativeness in individuals with Broca's aphasia (Zumbansen et al., 2014) and that dyslectic children, before music training, displayed significantly lower rates, compared to the non-dyslectic children in pitch discrimination tasks in speech. The ERP data also showed no pitch-discrimination response for the dyslectics. However, after they received 6-month of musical training, the results revealed that their pitch-discrimination rates in speech were similar with the non dyslectic children, as well as the activation of the ERP components. Thus, since there are transfer effects from language to music in clinical cases, it might be that the representations of specific domains are impaired, while the developmental processes share common cognitive resources. This argument might also stand for the pitch mechanism among language and music. Future clinical cross-domain approaches from cases such as, aphasia and amusia might offer a better understanding on the interaction of language and music.

In sum, the idea of shared processing resources among distinct cognitive domains may be linked with the general principles of the organization of the human brain. And it is that the brain functions in the most economical way in terms of energy resources to minimize the cognitive costs (Bullmore & Sporns, 2012). Thus, since linguistic pitch shares common acoustical properties with music pitch (pitch contrasts that are distinguished by frequency in scales from low to high), I assume that there are domain-general mechanisms among different functions such as, language and music that do not demand separate cognitive resources, reducing potential energy costs. One of those shared mechanisms could be pitch, at least during the early acoustical decoding information level and before the topological transition of shaping domain-specific representations.

References

Ayotte, J., Peretz, I., & Hyde, K. (2002). Congenital amusia: A group study of adults afflicted with a music-specific disorder. *Brain*, *125*(2), 238-251.

Bautista, R. E. D., & Ciampetti, M. Z. (2003). Expressive aprosody and amusia as a manifestation of right hemisphere seizures. *Epilepsia*, *44*(3), 466-467.

Besson, M., Schön, D., Moreno, S., Santos, A., & Magne, C. (2007). Influence of musical expertise and musical training on pitch processing in music and language. *Restorative neurology and neuroscience*, *25*(3-4), 399-410.

Bidelman, G. M., Gandour, J. T., & Krishnan, A. (2011). Cross-domain effects of music and language experience on the representation of pitch in the human auditory brainstem. *Journal of cognitive neuroscience*, *23*(2), 425-434.

Bullmore, E., & Sporns, O. (2012). The economy of brain network organization. *Nature Reviews Neuroscience*, *13*(5), 336-349.

Chen, X., Zhao, Y., Zhong, S., Cui, Z., Li, J., Gong, G., ... & Nan, Y. (2018). The lateralized arcuate fasciculus in developmental pitch disorders among mandarin amusics: left for speech and right for music. *Brain Structure and Function*, *223*(4), 2013-2024.

Chomsky, N. (1957). Syntactic Structures Mouton. *The Hague*, *19573*.

Chomsky, N. (1965). Aspects of the theory of syntax Cambridge. *Multilingual Matters: MIT Press*.

Chomsky, N. (1991). Linguistics and cognitive science: Problems and mysteries.

Confavreux, C., Croisile, B., Garassus, P., Aimard, G., & Trillet, M. (1992). Progressive amusia and aprosody. *Archives of Neurology*, *49*(9), 971-976.

Douglas Bates, Martin Maechler, Ben Bolker, Steve Walker (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. doi:10.18637/jss.v067.i01.

Fedorenko, E., Patel, A., Casasanto, D., Winawer, J., & Gibson, E. (2009). Structural integration in language and music: evidence for a shared system. *Memory & cognition*, *37*(1), 1-9.

Foxton, J. M., Dean, J. L., Gee, R., Peretz, I., & Griffiths, T. D. (2004). Characterization of deficits in pitch perception underlying 'tone deafness'. *Brain*, *127*(4), 801-810.

Frances, R., Lhermitte, F., & Verdy, M. F. (1973). Musical deficit among aphasics. *International Review of Applied Psychology*.

Frazier, L. (1978). On comprehending sentences: Syntactic parsing strategies. *Doctoral dissertation, University of Connecticut*.

Hausen, M., Torppa, R., Salmela, V. R., Vainio, M., & Särkämö, T. (2013). Music and speech prosody: a common rhythm. *Frontiers in psychology*, *4*, 566.

Hutchins, S., Gosselin, N., & Peretz, I. (2010). Identification of changes along a continuum of speech intonation is impaired in congenital amusia. *Frontiers in psychology*, *1*, 236.

Hyde, K. L., & Peretz, I. (2004). Brains that are out of tune but in time. *Psychological Science*, *15*(5), 356-360.

Hyde, K. L., Lerch, J. P., Zatorre, R. J., Griffiths, T. D., Evans, A. C., & Peretz, I. (2007). Cortical thickness in congenital amusia: when less is better than more. *Journal of Neuroscience*, *27*(47), 13028-13032.

Hyde, K. L., Zatorre, R. J., & Peretz, I. (2011). Functional MRI evidence of an abnormal neural network for pitch processing in congenital amusia. *Cerebral Cortex*, *21*(2), 292-299.

Jackendoff, R. (1997). *The architecture of the language faculty* (No. 28). MIT Press.

Jiang, C., Hamm, J. P., Lim, V. K., Kirk, I. J., & Yang, Y. (2010). Processing melodic contour and speech intonation in congenital amusics with Mandarin Chinese. *Neuropsychologia*, *48*(9), 2630-2639.

Jiang, C., Hamm, J. P., Lim, V. K., Kirk, I. J., & Yang, Y. (2012). Impaired categorical perception of lexical tones in Mandarin-speaking congenital amusics. *Memory & cognition*, *40*(7), 1109-1121.

Knickerbocker, K. G. (2007). Revisiting the language-music relationship: exploring pitch recognition and discourse intonation in adult ESL students.

Koelsch, S., Gunter, T. C., von Cramon, D. Y., Zysset, S., Lohmann, G., & Friederici, A. D. (2002). Bach speaks: A cortical" language-network" serves the processing of music. *Neuroimage*, *17*(2), 956-966.

Koelsch, S., Gunter, T. C., Wittfoth, M., & Sammler, D. (2005). Interaction between syntax processing in language and in music: An ERP study. *Journal of cognitive neuroscience*, *17*(10), 1565-1577.

Kotilahti, K., Nissilä, I., Näsi, T., Lipiäinen, L., Noponen, T., Meriläinen, P., ... & Fellman, V. (2010). Hemodynamic responses to speech and music in newborn infants. *Human brain mapping*, *31*(4), 595-603.

Krishnan, A., Bidelman, G. M., Smalt, C. J., Ananthakrishnan, S., & Gandour, J. T. (2012). Relationship between brainstem, cortical and behavioral measures relevant to pitch salience in humans. *Neuropsychologia*, *50*(12), 2849-2859.

Levitin, D. J., & Menon, V. (2003). Musical structure is processed in “language” areas of the brain: a possible role for Brodmann Area 47 in temporal coherence. *Neuroimage*, *20*(4), 2142-2152.

Liu, F., Jiang, C., Thompson, W. F., Xu, Y., Yang, Y., & Stewart, L. (2012). The mechanism of speech processing in congenital amusia: Evidence from Mandarin speakers. *PLos one*, *7*(2), e30374.

Liu, F., Patel, A. D., Fourcin, A., & Stewart, L. (2010). Intonation processing in congenital amusia: discrimination, identification and imitation. *Brain*, *133*(6), 1682-1693.

Lochy, A., Hyde, K. L., Parisel, S., Van Hyfte, S., & Peretz, I. (2004). Discrimination of speech prosody in congenital amusia. Poster presented at the 2004 meeting of the Cognitive Neuroscience Society, San Francisco.

Loui, P., & Wessel, D. (2006). Acquiring new musical grammars – A statistical learning approach. *International Conference on Music Perception and Cognition*, 1009-1017.

Loui, P., & Wessel, D. (2008). Learning and liking an artificial musical system: Effects of set size and repeated exposure. *Musicae Scientiae*, *12*(2), 207-230.

Loui, P. (2012). Learning and Liking of Melody and Harmony: Further Studies in Artificial Grammar Learning. *Topics in Cognitive Science*, *4,* 554-567.

Loui, P., Wessel, D., Hudson Kam, C., L. (2010). Humans Rapidly Learn Grammatical Structure in a New Musical Scale. *Music Perception*, *27(5),* 377-388.

Loui, P., Wu, E. H., Wessel, D. L., & Knight, R. T. (2009). A generalized mechanism for perception of pitch patterns. *Journal of Neuroscience*, *29*(2), 454-459.

Lu, X., Ho, H. T., Liu, F., Wu, D., & Thompson, W. F. (2015). Intonation processing deficits of emotional words among Mandarin Chinese speakers with congenital amusia: an ERP study. *Frontiers in Psychology*, *6,* 385.

Maess, B., Koelsch, S., Gunter, T. C., & Friederici, A. D. (2001). Musical syntax is processed in Broca's area: an MEG study. *Nature neuroscience*, *4*(5), 540-545.

Molino, J. (2000). *Toward an evolutionary theory of music and language*. The MIT Press.

Marin, O., and Perry, D. (1999). Neurological aspects of music perception and performance. In The Psychology of Music, D. Deutch, ed. (San Diego: Academic Press), pp. 653–724

Musacchia, G., Sams, M., Skoe, E., & Kraus, N. (2007). Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *Proceedings of the National Academy of Sciences*, *104*(40), 15894-15898.

Nan, Y., & Friederici, A. D. (2013). Differential roles of right temporal cortex and Broca's area in pitch processing: evidence from music and Mandarin. *Human brain mapping*, *34*(9), 2045-2054.

Nguyen, S., Tillmann, B., Gosselin, N., & Peretz, I. (2009). Tonal language processing in congenital amusia. *Annals of the New York Academy of Sciences*, *1169*(1), 490-493.

Nicholson, K. G., Baum, S., Kilgour, A., Koh, C. K., Munhall, K. G., & Cuddy, L. L. (2003). Impaired processing of prosodic and musical patterns after right hemisphere damage. *Brain and Cognition*, *52*(3), 382-389.

Papadopoulou, D., & Tsimpli, I. (2005). Morphological cues in children's processing of ambiguous sentences: A study of subject/object ambiguities in Greek. In *BUCLD 29: Proceedings of the 29th Annual Boston University Conference on Language Development*, 471-481, Cascadilla Press Somerville, MA.

Papangeli, A., & Marinis, T. (2010). Επεξεργασία δομικά αμφίσημων προτάσεων στην ελληνική ως Γ1 και ως Γ2. In *30th Annual Meeting of the department of Linguistics: school of Philology: Aristotele University of Thessaloniki*, 477-486.

Patel, A. D. (2003). Language, music, syntax and the brain. *Nature neuroscience*, *6*(7), 674-681.

Patel, A. D. (2010). *Music, language, and the brain*. Oxford university press.

Patel, A. D., Gibson, E., Ratner, J., Besson, M., & Holcomb, P. J. (1998). Processing syntactic relations in language and music: An event-related potential study. *Journal of cognitive neuroscience*, *10*(6), 717-733.

Patel, A. D., Peretz, I., Tramo, M., & Labreque, R. (1998). Processing prosodic and musical patterns: a neuropsychological investigation. *Brain and language*, *61*(1), 123-144.

Patel, A. D., Foxton, J. M., & Griffiths, T. D. (2005). Musically tone-deaf individuals have difficulty discriminating intonation contours extracted from speech. *Brain and cognition*, *59*(3), 310-313.

Patel, A. D., Wong, M., Foxton, J., Lochy, A., & Peretz, I. (2008). Speech intonation perception deficits in musical tone deafness (congenital amusia). *Music Perception*, *25*(4), 357-368.

Patel, R., Niziolek, C., Reilly, K., & Guenther, F. H. (2011). Prosodic adaptations to pitch perturbation in running speech.

Peretz, I., & Coltheart, M. (2003). Modularity of music processing. *Nature neuroscience*, *6*(7), 688-691.

Peretz, I., & Hyde, K. L. (2003). What is specific to music processing? Insights from congenital amusia. *Trends in cognitive sciences*, *7*(8), 362-367.

Peretz, I. (1993). Auditory atonalia for melodies. *Cognitive Neuropsychology*, *10*(1), 21-56.

Peretz, I. (2008). Musical disorders: From behavior to genes. *Current Directions in Psychological Science*, *17*(5), 329-333.

Peretz, I., Ayotte, J., Zatorre, R. J., Mehler, J., Ahad, P., Penhune, V. B., & Jutras, B. (2002). Congenital amusia: a disorder of fine-grained pitch discrimination. *Neuron*, *33*(2), 185-191.

Peretz, I., Champod, A. S., & Hyde, K. (2003). Varieties of musical disorders: the Montreal Battery of Evaluation of Amusia. *Annals of the New York Academy of Sciences*, *999*(1), 58-75.

Peretz, I., Kolinsky, R., Tramo, M., Labrecque, R., Hublet, C., Demeurisse, G., & Belleville, S. (1994). Functional dissociations following bilateral lesions of auditory cortex. *Brain*, *117*(6), 1283-1301.

Pfordresher, P. Q., & Brown, S. (2009). Enhanced production and perception of musical pitch in tone language speakers. *Attention, perception, & psychophysics*, *71*(6), 1385-1398.

Pickering, M. J., & Van Gompel, R. P. (2006). Syntactic parsing. In *Handbook of psycholinguistics*, 455-503, Academic Press.

Pinker, S. (1994). *The language instinct*. New York: William Morrow.

Radulescu, S., Wijnen, F., Avrutin, S. (2018). Patterns Bit by Bit. An Entropy Model for Rule Induction. *Language Learning and Development*, UiL-0TS, 1-46.

Randel, D. M. (1978). Harvard Concise Dictionary of Music. Cambridge, MA: Harvard University Press

Saussure, F. D. (1959). Course in General Linguistics, translated by R. *Basking. New York (First pubIisbed in 1916.)*.

Slevc, L. R., & Miyake, A. (2006). Individual differences in second-language proficiency: Does musical ability matter?. *Psychological science*, *17*(8), 675-681.

Slevc, L. R., Rosenberg, J. C., & Patel, A. D. (2009). Making psycholinguistics musical: Self-paced reading time evidence for shared processing of linguistic and musical syntax. *Psychonomic bulletin & review*, *16*(2), 374-381.

Stromswold, K., Caplan, D., Alpert, N., & Rauch, S. (1996). Localization of syntactic comprehension by positron emission tomography. *Brain and language*, *52*(3), 452-473.

Tillmann, B., Janata, P., & Bharucha, J. J. (2003). Activation of the inferior frontal cortex in musical priming. *Cognitive Brain Research*, *16*(2), 145-161.

Tomasello, M., Call, J., & Hare, B. (2003). Chimpanzees understand psychological states–the question is which ones and to what extent. *Trends in cognitive sciences*, *7*(4), 153-156.

Veenker, T.J.G. (2019). The Zep Experiment Control Application (1.17.1) [Computer software]. Beexy Behavioral Experiment Software. Retrieved from http://www.beexy.org/zep/

Van Rossum, G., & Drake, F. L. (2009). *Python 3 Reference Manual*. Scotts Valley, CA: CreateSpace.

Ullman, M. T., Corkin, S., Coppola, M., Hickok, G., Growdon, J. H., Koroshetz, W. J., & Pinker, S. (1997). A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of cognitive neuroscience*, *9*(2), 266-276.

Wong, P. C., Skoe, E., Russo, N. M., Dees, T., & Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature neuroscience*, *10*(4), 420-422.

Zatorre, R. J., & Baum, S. R. (2012). Musical melody and speech intonation: Singing a different tune. *PLoS Biol*, *10*(7), e1001372.

Zatorre, R. J., Belin, P., & Penhune, V. B. (2002). Structure and function of auditory cortex: music and speech. *Trends in cognitive sciences*, *6*(1), 37-46.

Zatorre, R. J., & Gandour, J. T. (2008). Neural specializations for speech and pitch: moving beyond the dichotomies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1493), 1087-1104.

Zumbansen, A., Peretz, I., & Hébert, S. (2014). The combination of rhythm and pitch can account for the beneficial effect of melodic intonation therapy on connected speech improvements in Broca's aphasia. *Frontiers in human neuroscience*, *8*, 592.

Appendix – Linguistic stimuli

Sentences are separated with "/" to precisely represent their onset during the task.

Practice items

1. Χθες/ενώ/έπαιζε/βιολί/η Άννα/έγραφε.
   Yesterday/while/(she/he) (was) playing-3rd-sing-/ violin-acc-/ Anna-nom-/ (was) writing-3rd-sing- .
   "Yesterday while (she/he) was playing the violin, Anna was writing"
   Question: Έπαιζε βιολί η Άννα; Όχι
   Was Anna playing the violin? No

2. Χθες/ενώ/ο καιρός/χειροτέρευε/πήγαν/πεζοπορία.
   Yesterday/while/the weather-nom-/was getting worse/(they) went/hiking.
   "Yesterday while the weather was getting worse, (they) went for hiking."
   Question: Πήγαν τελικά πεζοπορία; Ναι
   Did they finally go for hiking? Yes

Fillers

1. Χθες/ ενώ/ η παράσταση/ τελείωνε/ ο κόσμος/ καθόταν.

Yesterday/ while/ the act/ was ending/ the people-nom-/ were sitting.
"Yesterday while the act was ending, people were still sitting."
Question: Έφυγε ο κόσμος μετά την παράσταση;
"Did the people leave after the act?" No

2. Χθες/ενώ/μιλούσαν/Ρώσικα/ο Γιάννης/κατάλαβε.
   Yesterday/while/(they) were talking/Russian/John-nom/understood.
   "Yesterday while they were talking in Russian, John understood (them)."
   Question: Κατάλαβε ο Γιάννης τι έλεγαν; Ναι
   Did John understand what they were saying? Yes

3. Χθες/ενώ/κοιμόταν/η Κατερίνα/τον ξύπνησε/για φαγητό.
   Yesterday/while/(she/he) (was) sleeping/ Catherine-nom-/ woke up (him)/for food.
   "Yesterday while he was sleeping, Catherine woke him up for meal."
   Question: Κοιμόταν η Κατερίνα; Όχι
   Was Catherine sleeping? No

4. Χθες/ενώ/άκουγε/μουσική/διάβαζε/φιλοσοφία.
   Yesterday/while/(she/he) (was) listening/ music-acc/(she/he) (was) reading/philosophy.
   "Yesterday while (she/he) was listening to music, (she/he) was reading philosophy."

Question: Διάβαζε όταν άκουγε μουσική; Ναι
Was (she/he) reading while (she/he) was listening to music? Yes

5. Χθες/ενώ/ο Μιχάλης/γυμναζόταν/η Μαρία/γελούσε.
Yesterday/while/Michael-nom-/(was) exercising/Mary-nom-/(was) laughing.
"Yesterday while Michael was exercising, Mary was laughing"
Question: Γελούσε η Μαρία για το Μιχάλη;
Was Mary laughing for Michael? Yes

6. Χθες/ενώ/το δάσος/καιγόταν/οι κάτοικοι/προσεύχονταν.
Yesterday/while/the forest/ (was) burning/ the residents-nom-/(were) praying.
"Yesterday while the forest was burning, the residents were praying"
Question: Φοβήθηκαν οι κάτοικοι την φωτιά? Ναι
Did the residents scare the fire? Yes

7. Χθες/ενώ/τραγουδούσε/στην πλατεία/του επιτέθηκε/η αστυνομία.
Yesterday/while/(she/he) (was) singing-3rd-sin/in the square/ (him) attacked/the police.
"Yesterday while he was singing in the square, the police attacked him"
Question: Αναγκάστηκε να σταματήσει τη μουσική; Ναι
Was he forced to stop the music? Yes

8. Χθες/ενώ/η άγνωστη/τον πλησίαζε/άρχισε/να κλαίει.
Yesterday/while/the stranger-fem-nom/(him) approached/ (she) started-3rd-sin-/crying.
"Yesterday while the stranger approached him, she started crying"
Question: Έκλαιγε πριν δει την άγνωστη; Όχι
Was he crying before he saw the stranger? No

9. Χθες/ενώ/ταξίδευε/με πολύ αέρα/δεν υπήρχαν/αναταράξεις.
Yesterday/while/(he/she) (was) travelling-3rd-sin/with too much air/there were no/turbulences.
"Yesterday while (he/she) was travelling with windy weather, there were no turbulences."
Question: Υπήρχαν αναταράξεις λόγω κακοκαιρίας; Όχι
Were there any turbulences due to the foul weather? No

10. Χθες/ενώ/ο Γιώργος/διάβαζε/ο σκύλος του/γαύγιζε.
Yesterday/while/George/(was) reading-3rd-sin/his dog/ (was) barking.
"Yesterday while George was studying, his dog was barking"
Question: Γαύγιζε ο σκύλος του Γιώργου; Ναι
Was the dog of George barking? Yes

11. Χθες/ενώ/έκανε/το πείραμα/αναρωτήθηκε/το σκοπό του.

Yesterday/while/(he/she) (was) doing-3rd-sin/the experiment-acc/(he/she) wondered/ its purpose.
"Yesterday while (he/she) was doing the experiment, (he/she) wondered about its purpose."
Question: Αναρωτιόταν πριν ξεκινήσει το πείραμα; Όχι
Was (he/she) curious before (she/he) start the experiment? No

12. Χθες/ενώ/κολυμπούσε/η θάλασσα/σήκωσε/κύμα.
Yesterday/while/(he/she) (was) swimming-3rd-sin/the sea-nom/raised/wave.
"Yesterday while (he/she) was swimming, the sea raised waves"
Question: Είχε κύμα πριν; Όχι
Did it have waves earlier? No

13. Χθες/ενώ/διαμαρτύρονταν/χιλιάδες/δεν υπήρξε/κανένα επεισόδιο.
Yesterday/while/(were) striking-3rd-pl/thousands/there was not/any accident.
"Yesterday while thousands (of people) were striking, there was not any accident."
Question: Επειδή ήταν χιλιάδες σήμαινε ότι θα γίνει επεισόδιο; Όχι
Since there were thousands of people, was is it necessary that there will be an accident? No

14. Χθες/ενώ/οδηγούσε/το αμάξι/ανέβασε/θερμοκρασία.
Yesterday/while/(she/he) (was) driving-3rd-sin/the car-acc/nom/raised/temperature.
"Yesterday while (she/he) (was) driving, the car raised temperature."
Question: Φαίνεται να ανέβασε θερμοκρασία λόγω της οδήγησης; Όχι
Could that be that the temperature of the car was increased due to bad driving? No

15. Χθες/ενώ/έκανε/προπόνηση/στραμπούλιξε/το πόδι της.
Yesterday/while/(she) (was) doing-3rd-sin/training/ (she) twisted/ her leg.
"Yesterday while (she) was doing (her) training, she twisted her leg."
Question: Έγινε τη στιγμή της προπόνησης; Ναι
Did it happen during training? Yes

16. Χθες/ενώ/μιλούσαν/στο τηλέφωνο/ετοίμαζαν/μεσημεριανό.
Yesterday/while/(they) (were) talking-3rd-pl/on the phone/(they) (were) preparing/lunch.
"Yesterday while they were talking on the phone, they were preparing lunch."
Question: Ετοίμαζαν μεσημεριανό και οι δύο; Ναι
Were both preparing lunch? Yes

17. Χθες/ενώ/έγραφε/στον υπολογιστή/του έπεσε/το τσάι.
Yesterday/while/(he) (was) typing-3rd-sin/on the pc/ (he) dropped/the tea.

"Yesterday while he was typing on the pc, he dropped the tea."
Question: Έπεσε το τσάι στον υπολογιστή; Όχι
Did the tea drop on the pc? No

18. Χθες/ενώ/έτρεχε/στο πάρκο/την σταμάτησαν/για έλεγχο.
Yesterday/while/(she)was running-3rd/sin/in the park/(they) stopped (her)/for inspection.
"Yesterday while she was running in the park, they stopped her for inspection"
Question: Την σταμάτησαν ενώ είχε πάει για τρέξιμο; Ναι
Do they stopped her while she was out for running? Yes

Test items - latin square design

Ambiguous Conditions (all the verbs of the first VP of the experimental sentences are optionally transitive in Greek)

1. Χθες/ενώ/μαγείρευε/τα ψάρια/κάηκαν/στον φούρνο.
Yesterday/while/(he/she) (was) cooking-3rd-sin/the fish-nom/acc-pl/burnt-3rd-pl/in the oven.
"Yesterday while (he/she) was cooking(,) the fish burnt in the oven)
Question: Μαγείρευε μόνο τα ψάρια; Όχι
Was (she/he) cooking only fish? No

2. Χθες/ενώ/έπλενε/τα γατάκια/κυνηγούσαν/το νερό.
Yesterday/while/(he/she) (was) washing-3rd-sin/the cats-nom/acc-pl/(were) chasing/the water.
"Yesterday while (she/he) was washing(,) the cats were chasing the water."
Question: Έπλενε τα γατάκια; Όχι
Was (she/he) washing the cats? No

3. Χθες/ενώ/έβριζε/τα ζάρια/έφεραν/εξάρες.
Yesterday/while/(she/he) (was) cursing-3rd-sin/the dice-acc/nom-pl/brought/six.
"Yesterday while (he/she) was cursing(,) the dice brought six."
Question: Έφεραν εξάρες τα ζάρια; Ναι
Did the dice bring six? Yes

4. Χθες/ενώ/γεννούσε/τα σκυλάκια/γαύγιζαν/στον κήπο.
Yesterday/while/(she/he/it) (was) giving birth/ the puppies-nom/acc-pl/were barking/in the garden.
"Yesterday while (she/he) was giving birth(,) the puppies were barking in the garden."

5. Χθες/ενώ/κοιτούσε/τα παιδιά/έπεσαν/από το μπαλκόνι.

Yesterday/while/(she/he) (was) looking/the children-nom/acc/fell-3rd-pl/from the balcony.
"Yesterday while (she/he) was looking(,) the children fell from the balcony"
Question: Κοιτούσε τα παιδιά; Όχι
Was she/he looking at the children? No

6. Χθες/ενώ/ονειρευόταν/τα αστέρια/έπεφταν/ακατάπαυστα.
Yesterday/while/(she/he) was dreaming/ the stars-acc/nom/were falling/interminably.
"Yesterday while (she/he) was dreaming(,) the stars were falling interminably."
Question: Ονειρευόταν κάτι διαφορετικό από τα αστέρια; Ναι
Was she/he dreaming anything different rather than the stars? Yes

7. Χθες/ενώ/ζωγράφιζε/τα λουλούδια/μαράθηκαν/στο βάζο.
Yesterday/while/(she/he) (was) painting/the flowers-acc/nom/wilted-3rd-pl/in the vase.
"Yesterday while she/he was painting(,) the flowers wilted in the vase."
Question: Μαράθηκαν τα λουλούδια στο βάζο; Ναι
Did the flowers wilt in the vase? Yes

8. Χθες/ενώ/κοιμόταν/τα παιδιά/έτρεχαν/στο πάρκο.
Yesterday/while/(they) (were) sleeping(optionally transitive)/the children-acc/nom/ were running/in the park.
"Yesterday while they were sleeping(,) the children were running in the park."
Question: Κοιμόταν τα παιδιά; Όχι
Were the children sleeping? No

9. Χθες/ενώ/έβαφε/τα κουτιά/ακούμπησαν/στον τοίχο.
Yesterday/while/(she/he) was painting/the boxes acc/nom/ layed 3rd-pl/ on the wall.
"Yesterday while she/he was painting(,) the boxes layed on the wall.
Question: Έβαφε κάτι διαφορετικό από τα κουτιά; Ναι
Did she/he paint anything different than the boxes? Yes

10. Χθες/ενώ/τηγάνιζε/τα κολοκύθια/κάηκαν/στην κατσαρόλα.
Yesterday/while/(she/he) was frying/the zucchinis acc/nom/pl/burnt-3rd/pl/in the pot.
"Yesterday while she/he was frying(,) the zucchinis burnt in the pot"
Question: Τηγάνιζε κάτι διαφορετικό από τα κολοκύθια; Ναι
Was she/he frying something different than the zucchinis? Yes

11. Χθες/ενώ/καθάριζε/τα κάστανα/ψήνονταν/στο τζάκι.

Yesterday/while/(she/he) was cleaning/the chestnuts-acc/nom/were roasting/in the fireplace.
“Yesterday while she/he was cleaning(,) the chestnuts were roasting in the fireplace”
Question: Καθάριζε τα κάστανα; Όχι
Was he/she cleaning the chestnuts? No

12. Χθες/ενώ/φωτογράφιζε/τα κορίτσια/έπαιζαν/πιάνο.
Yesterday/while/she/he was photographing/the girls-acc/nom/were playing/the piano.
“Yesterday while she/he was photographing(,) the girls were playing the piano.”
Question: Έπαιζαν πιάνο τα κορίτσια; Ναι
Were the girls playing the piano? Yes

Non Ambiguous - Control Conditions (This is the non ambiguous version of the experimental sentences)

1. Χθες/ενώ/μαγείρευε/τα ψάρια/κάηκε/στον φούρνο.
Yesterday/while/(he/she) (was) cooking-3rd-sin/the fish-nom/acc-pl/(he)/she burnt-3rd-sin/in the oven.
“Yesterday while (he/she) was cooking the fish (he/she) burnt in the oven)
Question: Κάηκαν τα ψάρια στο φούρνο; Όχι
Were the fish burnt in the oven? No

2. Χθες/ενώ/έπλενε/τα γατάκια/τέλειωσε/το νερό.
Yesterday/while/(she/he) was washing/the cats-acc/finished/the water.
“Yesterday while she/he was washing the cats(,) the water finished.”
Question: Έπλενε κάτι άλλο πέρα από τα γατάκια; Όχι
Was she/he washing something else, instead of the cats?

3. Χθες/ενώ/έβριζε/τα ζάρια/έφερε/εξάρες.
Yesterday/while/(she/he) (was) cursing-3rd-sin/the dice-acc-pl/(she/he) brought/six.
“Yesterday while he/she was cursing the dice he/she brought six.”
Question: Έβριζε τα ζάρια; Ναι
Did she/he curse the dice? Yes

4. Χθες/ενώ/γεννούσε/τα σκυλάκια/γαύγιζε/στη γάτα.
Yesterday/while/(it) was giving birth/ the puppies-acc-pl/(it) was barking/to the cat.

“Yesterday while (she/he) was giving birth(,) the puppies were barking in the garden.”
Question: Γαύγιζε γιατί γεννούσε; Όχι
Was it barking because it was giving birth? No

5. Χθες/ενώ/κοιτούσαν/το παιδί/έπεσαν/από το μπαλκόνι.
Yesterday/while/(they) were looking/the child-acc/ (they) fell-3rd-pl/from the balcony.
“Yesterday while they were looking the child they fell from the balcony”
Question: Έπεσε το παιδί από το μπαλκόνι; Όχι
Did the child fall from the balcony? No

6. Χθες/ενώ/ονειρευόταν/τα αστέρια/έπεσε/στο πάτωμα.
Yesterday/while/(she/he) was dreaming/ the stars-acc/ (she/he) fell/on the floor.
“Yesterday while (she/he) was dreaming the stars (she/he) fell on the floor.”
Question: Ονειρευόταν τα αστέρια; Ναι
Was she/he dreaming the stars? Yes

7. Χθες/ενώ/ζωγράφιζε/τα λουλούδια/ράγισε/το βάζο.
Yesterday/while/(she/he) (was) painting/the flowers-acc/cracked-3rd-sin/the vase.
“Yesterday while she/he was painting the flowers the vase wilted”
Question: Ζωγράφιζε τα λουλούδια;; Ναι
Was she/he painting the flowers? Yes

8. Χθες/ενώ/κοιμόταν/τα παιδιά/έτρεχε/στο πάρκο.
Yesterday/while/(they) (were) sleeping(optionally transitive)/the children-acc/ (she/he) (was) running/in the park.
“Yesterday while the children were sleeping she/he was running in the park.”
Question: Έτρεχαν τα παιδιά στο πάρκο; Όχι
Were the children running in the park? No

9. Χθες/ενώ/έβαφε/τα κουτιά/ακούμπησε/τον τοίχο.
Yesterday/while/(she/he) was painting/the boxes acc/ (she/he) layed 3rd-sin/ on the wall.
“Yesterday while she/he was painting the boxes she/he layed the wall.”
Question: Λέρωσε τον τοίχο όταν έβαφε τα κουτιά; Ναι
Did she/he lay the wall while he/she was painting the boxes? Yes

10. Χθες/ενώ/τηγάνιζε/τα κολοκύθια/κάηκε/στην κατσαρόλα.
Yesterday/while/(she/he) was frying/the zucchinis ac-pl/ (she/he) (was) burnt-3rd-sin/in the pot.

"Yesterday while she/he was frying the zucchinis she/he was burnt in the pot"
Question: Κάηκε στην κατσαρόλα όταν τηγάνιζε κολοκύθια; Ναι
Was she/he burnt in the pot while she/he was frying the zucchinis? Yes

11. Χθες/ενώ/καθάριζε/τα κάστανα/καθόταν/στο τζάκι.
Yesterday/while/(she/he) was cleaning/the chestnuts-acc/(she/he) was sitting/in the fireplace.
"Yesterday while she/he was cleaning the chestnuts she/he was sitting in front of the fireplace"
Question: Έκαψε τα κάστανα στο τζάκι; Όχι
Did she/he overbaked the chestnuts in the fireplace?

12. Χθες/ενώ/φωτογράφιζε/τα κορίτσια/εστίαζε/στο πιάνο.
Yesterday/while/she/he was photographing/the girls-acc/(she/he) was focusing/on the piano.
"Yesterday while she/he was photographing the girls she/he was focusing on the piano."
Question: Στη φωτογραφία εστίαζε στο πιάνο; Ναι
While she/he was photographing did she/he focus on the piano? Yes

Test items – within subject design

Ambiguous Conditions (all the verbs of the first VP of the experimental sentences are optionally transitive in Greek)

1. Χθες/ενώ/έτρωγε/τα ψίχουλα/έπεσαν/στο πάτωμα.
   Yesterday/while/(she/he) was eating/the crumbs-nom/acc/fell-3rd-pl/on the floor.
   "Yesterday while she/he was eating(,) the crumbs fell on the floor."
   Question: Έτρωγε τα ψίχουλα που έπεσαν στο πάτωμα; Όχι
   Was she/he eating the crumbs that fell on the floor? No

2. Χθες/ενώ/ηχογραφούσαν/τα βιολιά/ακούγονταν/παράφωνα.
   Yesterday/while/(they) were recording/the violins-acc/nom/were sounding/out of tune.
   "Yesterday while they were recording(,) the violins were sounding out of tune.
   Question: Τα βιολιά ακούγονταν παράφωνα; Ναι
   Were the violins sounding out of tune?

Non Ambiguous - Control Conditions (This is the non ambiguous version of the experimental sentences)

1. Χθες/ενώ/έτρωγε/τα ψίχουλα/έπεσε/στο πάτωμα.
   Yesterday/while/(she/he) was eating/the crumbs-acc/(she/he) fell-3rd-sin/on the floor.
   "Yesterday while she/he was eating the crumbs(,) she/he fell on the floor."
   Question: Είχε πέσει στο πάτωμα πριν φάει τα ψίχουλα; Όχι
   Had she/he fallen on the floor before she/he ate the crumbs? No

2. Χθες/ενώ/ηχογραφούσε/τα βιολιά/άκουγε/παρατονίες.
   Yesterday/while/(he/she) was recording/the violins-acc/(he/she) was hearing/mistunes-acc.
   "Yesterday while he/she was recording the violins he/she was hearing mistunes.
   Question: Άκουγε παρατονίες καθώς ηχογραφούσε; Ναι
   Was she/he hearing mistunes while she/he was recording? Yes